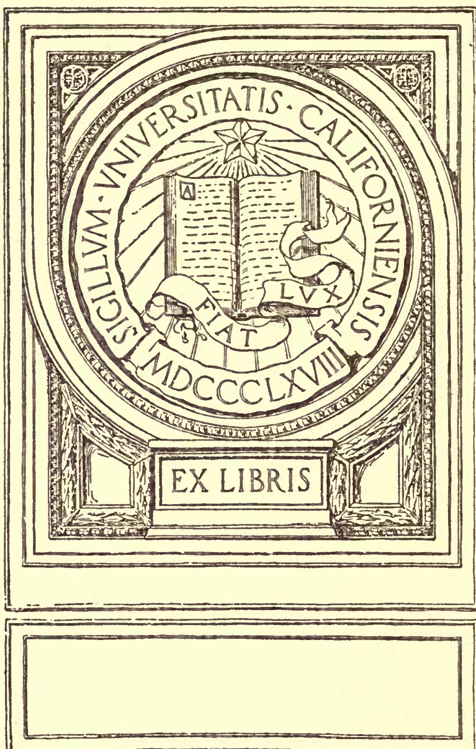
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AVIATION

THEORICO-PRACTICAL TEXT-BOOK FOR STUDENTS

BY

BENJAMIN M. CARMINA

ASSISTANT CHIEF INSTRUCTOR AT THE Y. M. C. A. AIRPLANE MECHANICS' SCHOOL, CHARTER MEMBER AND LECTURER OF THE AËRONAUTICAL SOCIETY

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TO

THE GENIUS OF MAN

THE CORRECTOR OF NATURE

THE CREATOR OF WINGS

THAT BEAT BIRD AND WIND

PREFACE

In the compilation of this book, the guiding principle has been to use matter of actual theorico-practical value to the aviation students to enable them to work knowingly.

For a given aëroplane part, the most common term has been chosen out of the maze of confusing terminology, which ought to have been relegated into oblivion long ago to facilitate the study of one of the greatest, if not the greatest, products of the human mind. Admittedly, the aëroplane is in its infancy, but an infant that can go at such a high rate of speed and perform such marvelous feats certainly deserves more than passing attention, and it is high time to standardize the names of its parts, at least. Although wrong as any other, the term "plane" has been used to designate a wing or a wing-like structure, because it is incorporated in the very word "aëroplane," and to have introduced a new and proper term would have meant the changing of even the name of the machine, thus creating more confusion.

The appendix has been added for the benefit of the students who wish to go deeper into the science of aërodynamics, and to facilitate the task of those who have not the necessary mathematical knowledge, the superficial elements of algebra, trigonometry and the metric system have been given in the definitions.

It is hoped that this treatise will fill the long felt want of a theorico-practical text-book on aviation.

THE AUTHOR.

CONTENTS

AVIATION

AVIATION

CHAPTER I

THEORY OF FLIGHT

Planes

Aviation is the branch of aëronautics that treats of the gasless aircraft.

The fundamental law governing aviation is based on the resistance of the air against a body moving through it.

Man's first application of this law to obtain flight is found in the use of the kite, which is in reality the forerunner of the aëroplane.

In analyzing the process of kite flying, we find that, in order to accomplish flight, a natural current of air must blow against the kite or the kite must be dragged through the air generating its own artificial current, and that in either case the kite must be at an angle with the horizon and not in a vertical position. While it is immaterial, therefore, whether the air attacks the kite or the kite attacks the air, it is imperative that the kite be at an angle with the horizon or there will be no flight. From experience, we know this to be so; now let us see why.

Flat Planes.—If we move through the air a normal plane, it simply pushes the air back without accomplishing any work, because the air meets the plane perpendicularly and slips off all around the edges evenly. The air pushed back by the plane will exercise against it a certain resistance with a consequent pressure, whose center will be in the center of figure. If we double the speed of the plane, the plane will displace double the amount of air and the air will strike the

plane with double the force, so that the resultant resistance will be the product of two times the mass of air engaged by two times its striking force, that is, four times as great as before or equal to the first amount of resistance multiplied by the square of two. If we treble the speed, the plane will engage three times the amount of air, the air will strike the plane with three times the force and the result will be nine times greater or equal to the first amount of resistance by the product of three times three or the square of three; and so forth. We can say, therefore, that the resistance of the air to a normal plane moving through it is proportional to the surface of the plane and to the square of the velocity. Properly speaking, for very high speeds the resistance increases at a greater rate than the square of the velocity, until we reach the 5th power at about 800 miles per hour, when it begins to diminish until it becomes less than the square, but for all practical purposes, we may say that the square law holds good.

If we now move through the air an inclined plane *A B* (Fig. 1), the air strikes the under side of the plane and flows downward perpendicularly. In so doing, while it tries to force the plane backward, in the meantime, forces it upward. In this case, the center of pressure *P* is toward the front, because the front part of the plane does most of the work, as it engages undisturbed air. We may consider this resultant force *P* divided in its two components *L* and *D*, the first acting in a vertical direction and pushing the plane upward, the second in a horizontal direction and pushing the plane backward. The vertical component is the lift and the horizontal, the drift.

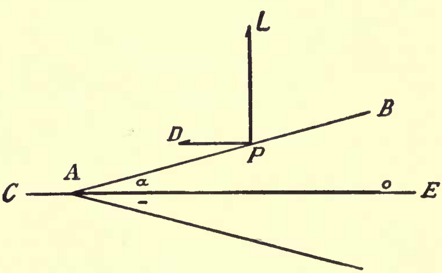


Fig. 1

The angle a formed by the plane $A\ B$ with the horizontal $C\ E$ is the angle of incidence. If we lower the front edge of the plane still further until it is horizontal, then the angle of incidence will be zero; and if we continue to lower it still more, the angle formed by the plane below the horizontal will be a negative angle of incidence.

The resistance of the air, against an inclined plane moving through it, is proportional to the surface, the square of the velocity and the sine of the angle of incidence.

Flat planes do not give good results, because the air meeting the plane is shot down vertically and the rear part does little work, as it engages air which has already a downward trend, besides the fact that the air rushing past the entering edge of the plane carries away part of the air in the rear of it, causing a partial vacuum, which renders easier the work of the pressure of the air in front of the plane in pushing it back and resulting, therefore, in greater drift. In this connection, the arrangement of planes which deserves special attention is the tandem arrangement, because it explains the increased lift of curved planes.

If we place three planes, equal in shape, dimension and inclination, one after the other in a straight line and drive them through the air, we find that the first plane lifts a great deal more than the second and the third respectively. The reason for this marked falling off in the lift of the rear planes is that they have to engage the air, which was already pushed downward by the preceding ones and therefore caused to meet the rear planes with a different horizontal velocity than it met the forward planes.

It is evident that if we want to use the tandem arrangement, we have to dispose the planes so that the rear ones will be able to engage undisturbed air, and to do this, we have to place the second plane lower than the first, and the third lower than the second; that is, in steps. This difference in level must be proportional to the size of the planes, so that the air moved by the preceding ones will pass above

the rear planes. The best disposition will be attained when the sum of all the spaces between the planes is equal to the whole area occupied by the planes. In this way, we will be able to produce a large lift per unit of surface and a relatively low drift.

But we can dispose the same planes in another way, which is just as effective as the step formation and which, incidentally, leads us to the formation of the curved planes.

Cambered Planes.—As we have just seen, an inclined plane, moving through the air, leaves it at the rear edge with a downward motion; if we, therefore, want to use two or more planes one after the other, we have to place the rear planes at a greater angle than the preceding ones, so as to engage the air already pushed downward by the latter.

Suppose that *A B* (Fig. 2) is a plane inclined at an angle of 6°; if we drive it forward, it is clear that the air will flow away at *B* with a downward trend; so, if we want to use another plane *C D* behind it, we will have to put it at a greater angle, say 10°, and if we want to add a third plane *E F*, we have to set it at a greater angle than the second plane, say 12°. As there is no reason why we should use three planes instead of one, which will answer the same purpose, we can substitute for the three planes *A B*, *C D*, *E F*, the plane *A F*, which will have the same shape formed by the other three, with the joints rounded off, so as to present a continuously curved stream-lined surface, that is, a surface so shaped as to exactly follow the contour of the line traced by the successive positions of a particle of fluid moving according to a determinate law. A stream-line is a continuous curve, as a fluid can not instantly change its direction of flow without forming a detrimental surface of discontinuity,

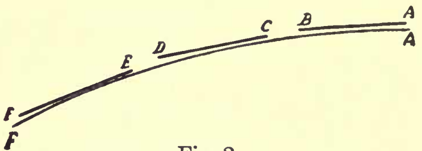


Fig. 2

as is the case with flat planes. This explains partly the reason why curved surfaces give more lift and relatively less drift than flat ones; and it explains it only partly because the planes used to-day have a double curvature, one above and one below, differing in degree and imitating the conformation of a bird's wing. Planes so shaped were at first used in mere imitation of nature, as in trying to realize man's dream of centuries, the conquest of the air, nothing was more natural than to imitate the only real, living flying machine in existence, the bird, but the attempt failed, not because the principle was wrong, but for the great disparity for unit weight between the muscular power of man and bird and for the multiplicity of parts needed, with the consequent friction, which would render uneconomical even the use of motors to accomplish flight through such a mechanism. But although the machine with the flapping wings, or ornithopter, was a failure, it played a very important part in the solution of the problem of aërial navigation, for it revealed to us the mysteries of the conformation of the bird's wing, whose construction we imitate in the design of the successful flying machine of to-day. The revelation of this natural secret, coupled with the knowledge of the laws that govern the flight of the kite, gave us the means to conquer the air.

If we move through the air a plane *A B* (Fig. 3), having an upper and lower camber as the planes used to-day, the leading edge *A* splits the air and forms two currents; one follows the lower camber and produces a compression, which resolves itself in lift and drift as in the flat plane, but, in the present case, it flows smoothly along the camber and gives the maximum lift, although the front part has more lift than the rear even in a cambered plane, as it engages always undisturbed air; the other current, striking the front part of the upper camber, glances upwards and, in rushing to the rear, carries with it the air lying between itself and the upper camber, causing in this way a rarefaction perpendicu-

lar to the plane and rendering more effective the pressure on the lower camber, which tries to equalize the difference

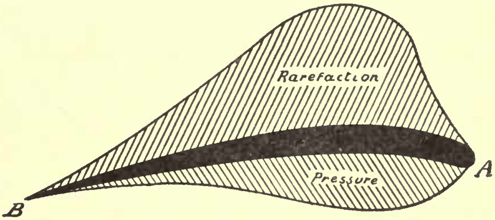


Fig. 3

in the density of the air above and below and produces a greatly increased lift. The greater amount of lift is due to the rarefaction on the upper camber, which in some planes is as much as 80 per cent, the balance, or 20 per cent, being given by the pressure on the lower camber, while the drift is simply the horizontal component of this pressure. From this, we see clearly why cambered planes are much better suited than flat ones to accomplish flight.

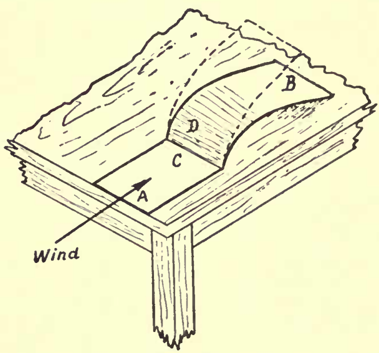


Fig. 4

A very simple experiment will conclusively prove the lift due to the upper camber.

If a sheet of paper *A B* (Fig. 4) is first folded, then opened, without flattening it out, and one part *C* is laid flat on a board, the other part *D* forms a curve behind the line of the fold; if we now hold the flat part and by mouth direct a stream of air parallel to it, the curved part rises and, if the current is strong, it jumps up.

In considering the lift and drift of a plane, we have to take into consideration its horizontal and vertical projections or

equivalents. The horizontal projection $A\ C$ of a plane $A\ B$ (Fig. 5) increases $A\ C'$ with a decrease in the angle of incidence, while its vertical projection $A\ D$ decreases $A\ D'$, and vice versa. The lift is proportional to the horizontal equivalent, the drift to the vertical equivalent. This means that the smaller the angle, the greater the lift, and the greater the angle, the greater the drift; but, on the other hand, the increase of the angle causes the plane to engage more air, and as in reality it is the product of the two that must count, that is, the surface of the plane and the mass of air, an increase of angle means an increase of lift besides an increase of drift, so that at a certain angle the two forces will balance. The best proportion of lift to drift, or lift drift ratio, is found for small angles, as, in this case, the proportion of the horizontal equivalent to the vertical equivalent is the highest. In other words, the nearer the plane comes to the vertical, the greater the drift and, consequently, the greater the power needed to overcome it, and vice versa; which means that the theory of the plane set at an angle is the same as the old known theory of the inclined plane.

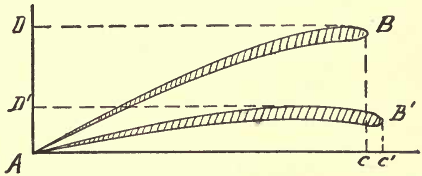


Fig. 5

Let us make this clearer. If the greatest weight that a man can lift in a perpendicular line to a height of two feet is 150 pounds and he has to lift a greater weight, he usually resorts to the use of a plank, by putting one end of it on the point where he wants to raise the weight and the other end on the ground, and rolling on it the given weight to the given height. As weight means gravity, it is clear that in this case the power employed to lift the weight is less than that of gravity, and, consequently, the use of the inclined plane is very economical in the expenditure of power. For this very reason, the solution of the problem of aërial

navigation by means of the helicopter, or machine intended to fly by means of horizontal propellers which would raise it straight up from the ground, has not been possible so far, as such a machine, to leave the ground, must produce first of all a vertical force powerful enough to overcome that of gravity, and this without considering the power lost in consequence of the extreme fluidity of the air. Other considerations are against the use of the helicopter. Even admitting that a motor so light and powerful could be found to accomplish flight by such means, it is necessary to use at least two propellers, because if only one were used, the propeller torque, or rotary force of the propeller, would cause the machine to revolve in an opposite direction. Then again, once the machine is raised from the ground, another propeller would be necessary to make it move in a horizontal direction or the machine should be tilted so that the same propellers that raise it, cause it to move horizontally. And finally, supposing that flight could be accomplished by means of a helicopter, there is to consider the ever present possibility of the stoppage of the motor, in which case the machine would tumble down like a plummet. In opposition to this and in further confirmation of the great superiority of the machine using the inclined plane for its sustentation in the air, we will cite the case of the glider used in the experimental stages of aërial navigation, which was sufficient to raise into the air the weight of a man by means of his muscular power; and the glider was nothing but a flying machine without motor and propeller.

In regard to the shape of the curvature of cambered planes, the best suited is the parabolic curve, with its highest point near the front edge. This parabola, as soon as struck by the air, pushes it downward with a constant vertical velocity, without interference with the following masses of air, in this way increasing the lift and decreasing the drift.

As to the degree of curvature, no definite rule can be given, because it must vary according to the speed of the

machine; the curvature being smaller, the speedier the machine, in order to decrease the drift. From this, it follows that the rule set by the great, unlucky pioneer, Lilienthal, that the curvature be 1/12 of the chord of the arc, can not be applied generally. Most likely this conclusion was reached through the study of bird wings, but evidently we could not properly compare them with the planes of a machine, as the birds use their wings both for flapping and gliding, while we use the planes for gliding only. That the same curvature would be successful for both cases is, therefore, out of the question.

The angle of incidence of the cambered planes is of the greatest importance; the plane must be set so that, in splitting the air, it allows the latter to flow above and below without disturbing its continuity. What this angle is to be, it must be arrived at according to the shape of the plane.

From the foregoing, it is clear that nothing is established with certainty as yet in regard to cambered planes, and, therefore, we must be guided by actual experience to find the best angle of incidence and the center of pressure, which differ with the degree of curvature.

Owing to the camber of the planes, it would be impossible to measure the angle of incidence, which would vary at different points, unless some means were found to make it equal throughout and this is accomplished by using the chord or straight line *A B* (Fig. 6*a*) drawn from the leading to the trailing edge, but, in this case, when the angle of incidence is zero, that is, when the chord is parallel with the horizontal or line of flight, the plane has still lift, due to the upper camber and, consequently, the real zero angle for cambered planes must be below that given by the chord. This point is found by experiment in the wind tunnel by lowering the leading edge *D* (Fig. 6*b*) of the plane, until it is in such a position that there is no lift. Then, a line *C E* drawn from the trailing edge through the width of the plane, parallel to the line of flight, will be the neutral line.

This, therefore, brings us to the consideration of two angles of incidence in a cambered plane; one $B\ A\ F$ (Fig. 6a) formed by the chord $A\ B$ with the line of flight $A\ F$, or rigger's angle of incidence, and the other $G\ A\ F$ formed by the neutral line $A\ G$ with the line of flight $A\ F$, or flying angle of incidence.

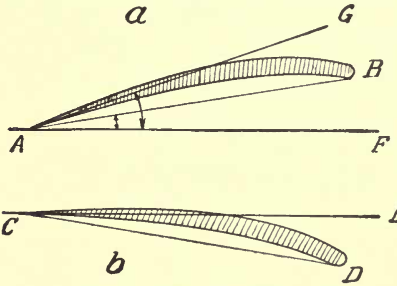


Fig. 6

For practical purposes, only the rigger's angle of incidence is used, as the neutral line is imaginary and we have no means to find it unless by experiment in the wind tunnel, while the chord can always be found. So, when we say that a plane is set at a zero angle of incidence, we mean that its chord is parallel with the line of flight, and if the plane is said to be at a negative angle of incidence, it means that the chord forms an angle below the line of flight.

The travel of the center of pressure in flat and cambered planes deserves our attention. If the front edge of a flat plane is lowered, the center of pressure moves forward and lifts the plane, and if the edge is raised, the center of pressure moves backward and lowers the plane. Flat planes, therefore, are stable. It is not so with cambered planes, because, on account of the two cambers, the center of pressure is the resultant of two forces and, consequently, it acts differently than in flat planes; that is, when the leading edge of a cambered plane is lowered, the center of pressure moves backward, and if it is raised, it moves forward. From this, it is clear that cambered planes are unstable, because if the leading edge rises, the center of pressure, moving forward, causes it to rise still more, and if it is lowered, the center of pressure moves backward and causes the plane to lower still more;

but although cambered planes are unstable, they are used because they give greater lift and smaller drift than flat planes.

Another factor of great importance entering in the consideration of lift is the proportion of the dimensions of the plane, that is, the ratio of length or span to width or chord, which constitutes its aspect ratio. The greater the proportion of span to chord, the greater the lift of the plane, because, as we know, the greatest part of the work is done by the front of the plane and again because all the air entering at the leading edge does not flow to the rear, but some of it is spilled at the lateral ends of the plane. The area of a plane, found by multiplying its dimensions, is not, therefore, the effective area, and for this reason, the plane must be much longer than it is wide. From this, it follows that the longer the plane, the better it would be in respect to lift, but of course there is a limit. The plane must be light and strong in the meantime, and we could not build a plane immensely long without increasing its weight beyond the limit imposed by the aërodynamical laws, for the reason that the volume, and therefore the weight, of a body increases as the cube of the linear dimensions, and the surface as the square of the dimensions, and, consequently, the relations between weight and surface would be completely disturbed. Therefore, it is better to have several superposed planes of reasonable dimensions, say 6 to 1, rather than one of great length. In regard to width, it is to be observed that while narrow planes give greater lift than wide ones, they do not offer the same safeguard in minimizing the fall of a flying machine in case of a compulsory glide from a height. As we see, therefore, there is a limit for both dimensions, span and chord.

If the span of a plane A (Fig. 7) is 30 feet and the chord is 6 feet, its aspect ratio is $30:6 = 5$. If we cut it in half lengthwise and we put the rear half B alongside the front half, then the aspect ratio would be $60:3 = 20$. The former would be a low aspect ratio and the latter a high aspect

ratio. While in both cases we have the same surface, the second plane would be much more efficient than the first,

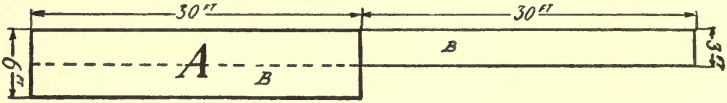


Fig. 7

because in taking the rear part of the plane, where it was doing very little work, and putting it in front, where it will do the greatest work, we have greatly increased the lift. Besides this, there is to consider the spill of air, which is halved, in the former plane taking place along two edges six feet long, and in the second along two edges only three feet long. For the same reason, if we were to turn the plane *A* so as to offer to the air the smaller side (Fig. 8), the lift would be immensely reduced, because of the great spill of air and the small section of the plane doing effective work in front. In conclusion, we may say that a high aspect ratio is the best, but, on the other hand, it would be impossible to build a plane with a very high aspect ratio, as it would be necessary to increase the thickness of the frame work used in the construction of planes to such a point, that what we would gain in lift, we would lose in weight. It is for this reason that we resort to the grouping of planes in superposed fashion. By arranging the planes in this way, we get about as much lift as with one long plane equal to the sum of their dimensions, a good saving in weight and great strength of construction.

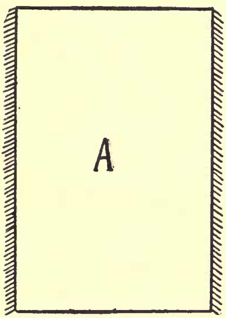


Fig. 8

In the arrangement of superposed planes, care should be taken to make the gap or interplane distance at least equal to their width, otherwise there will be interference and the lift will be diminished. Interference is the detrimental effect

produced in the gap by the rush of air, or wash, which disturbs both the rarefaction of the top camber of the lower plane and the compression of the lower camber of the upper plane. The greater loss of lift is in the lower plane, because in this case it is the rarefaction which is disturbed and we know that it is from the rarefaction that we get the greater

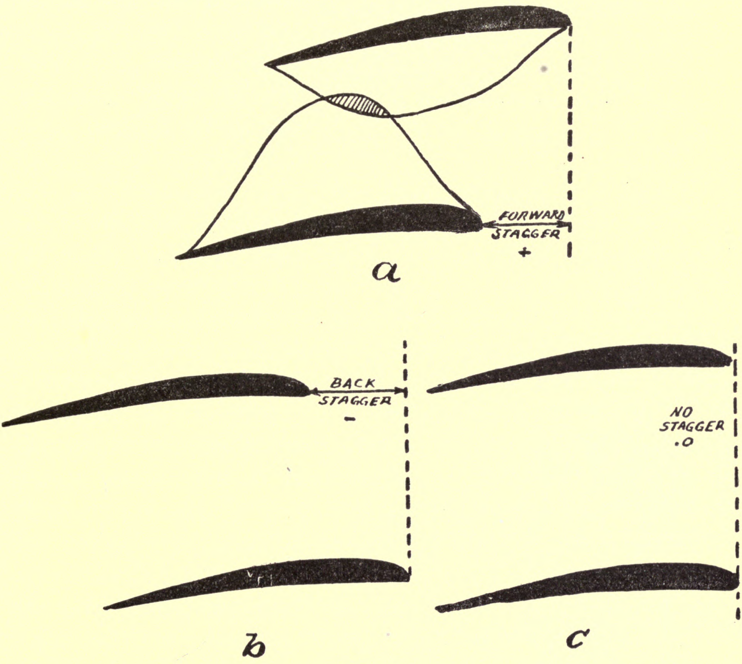


Fig. 9

amount of lift. For parity of surface, two superposed planes give about 15 per cent less lift than one single plane. The effect of interference could be eliminated by spacing the planes far apart one from the other, but as wooden sticks or struts are used to accomplish this, they should be made so thick that their weight and resistance would cause a loss instead of a gain. The best way to diminish interference as

far as possible, without unduly increasing the weight, is to stagger the planes, that is, to dispose them in steps (Fig. 9). If the top plane is forward of the lower plane, the stagger is positive (Fig. 9*a*); if the position is reversed, it is negative (Fig. 9*b*); and if there is no stagger at all, it is zero (Fig. 9*c*).

Sometimes in superposing planes, the top one is made longer (Fig. 10) as in this case the extension gives the full amount of lift, having no plane on the under side to produce interference.

Fig. 10

Active and Passive Drift.—We have considered so far the best angle and disposition of the planes without mentioning either the means to keep them rigidly in place to maintain the angle and disposition given or those to furnish the motive power. It is evident that a framework, an engine and a propeller are necessary to obtain our object. The embodiment of these different parts in a unit constitutes the aëroplane, which is, therefore, a power driven aircraft sustained in flight by the reaction of the air against planes set at an angle with the line of motion. It is distinguished as monoplane and multiplane, according to the number of superposed planes used; the biplane and triplane being simply particular cases of the multiplane.

The shape of an aëroplane very closely resembles that of a bird, both having a body, legs, wings and a tail, the only difference being that the bird has movable wings, which furnish both motive power and sustentation, while the aëroplane has rigid wings for sustentation only and the power is furnished by a motor, whose rotary motion is transformed into a linear motion by means of a propeller attached to it. As the machine moves through the air, there is resistance against the planes as well as against the framework. The resistance against the planes is active, as it gives lift besides drift, but the resistance against the other parts is

all passive drift and must be overcome in order to accomplish flight. To diminish this passive drift as much as possible, the different parts used in a machine are given a special shape, which has been found to be the best suited for the purpose.

If we move through the air a body *A B C D* (Fig. 11), having right-angled corners, the air, coming in contact with

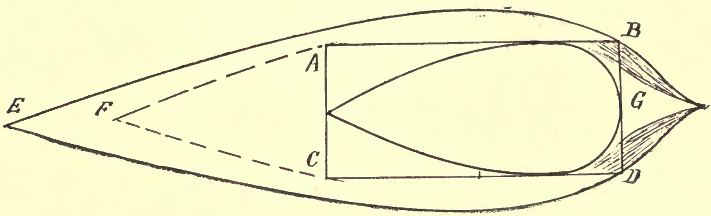


Fig. 11

the front part of the body, jumps off at the corners and falls toward the rear, until it meets again at a certain point *E*. Between this point and the rear part of the body a vacuum is formed which retards the forward motion of the body. This is due to the fact that the air meeting the corners can not instantly change its direction of flow and follow the shape of the body. If we round the front corners, the air, instead of jumping off, flows gradually along the curvature and the sides, meeting at a nearer point *F* in the rear. If we cut the sides tapering down to a point toward the rear, then the air follows exactly the contour of the body, eliminating the formation of the vacuum. The body will then be so shaped as to be blunt at the front part and thin at the rear. This is a stream-lined body and the ratio of length to width is its fineness. The fineness of a stream-lined body is proportional to the velocity, that is, the thinner the body the better suited to move through the air at a high velocity, because the air has less tendency to jump off in meeting the blunt part. If the body, instead of being rounded off at the front, had a sharp end, it would split the air more easily,

but this would be a loss instead of a gain, because when the air meets the blunt part and is split, it forms a vacuum *G*, which, being in the direction of motion, is beneficial, both because it helps move the body forward and because of the saving in the weight of material by cutting off the sharp edge. This small vacuum in front of a stream-lined body is known as Phillip's coefficient. When a body can not be stream-lined by cutting it into shape, then additional parts of wood, metal or fabric are used, so as to give it the proper form for least resistance.

Another factor which increases the passive drift is the skin friction. In regard to this point, there is a great deal of controversy, some authorities saying that it is due to the roughness of surface; others, that it is the rubbing of the air against the layer of air which surrounds all bodies and adheres to them even when in motion. While this point is still in doubt, what is positively known is that the coefficient of skin friction is inversely proportional to the area and the velocity, that is, the greater the surface and the greater the velocity, the smaller the amount of skin friction.

To still diminish the passive drift, advantage is taken of the shielding offered by one body on another following in its wake within certain limits. It has been found out by experiment that if two disks are placed one behind the other and a stream of air is directed against them, by moving the rear disk away from the front one and noting the drift given, at a distance of 1.50 times the diameter of one disk, the resistance of both is a minimum or 75 per cent of that of one single disk; then it increases to a medium at 2.15 diameters, becoming equal to that of one disk; and to a maximum at 10 diameters, equaling that of two disks. Why the resistance decreases instead of increasing from zero to 1.50 diameters, it is not very clear, but it seems that when the rear disk is moved backward that far, the eddy currents formed behind the front disk have the effect of pushing it forward with such a force as to diminish the backward pressure against both

disks; past that point, the eddies have less or no effect and the pressure increases, as it should.

In the practical application of the case of the disks to that of constructional parts, we have to take into consideration the dimensions of the sides exposed to the direction of motion. In other words, if the cross-sectional dimensions of two parts are 1 inch by 2 inches, and they are placed with the 1-inch side facing the direction of motion, the distance between them should be less than 10 inches or, if the other side is exposed, less than 20 inches to obtain a decrease in drift.

Evidently, it is not always possible to take full or even partial advantage of the shielding effect, owing to constructional requirements. We can conclude, therefore, that if it is possible to place parts of the framework of a machine at distances nearer than 10 times the dimensions offered to the direction of motion, there will be a reduction in passive drift, due to the shielding effect of one part on the other.

Stability

Equilibrium is the state of balance produced by the mutual counter action of two or more forces. Equilibrium is characterized by three phases: stable, unstable and indifferent or neutral. A body is in a state of stable equilibrium when, being disturbed, it tends to return to its previous position; in this state, the center of gravity of the body is in its lowest possible place. A body is in a state of unstable equilibrium when, being disturbed, it tends to move away from its previous position; in this state, the center of gravity of the body is in its highest possible place. A body is in a state of indifferent or neutral equilibrium when it will keep its balance independently of the position it is put in; in this state, the center of gravity of the body is at its center.

The best form of equilibrium is the neutral, but as it is

not always possible to attain it, the next step is to try to obtain the stable equilibrium.

From the standpoint of stability, the flying machine differs from any other form of locomotion. Being practically suspended in such a light and subtle fluid, as the air, the aëroplane is apt to move and oscillate in the direction of all its three axes: longitudinal, lateral and vertical; and consequently its stability must be considered in connection with these three phases; that is, the longitudinal, the lateral and the directional stability. The lateral stability, again, must be considered in regard to straight flight and circular flight.

Longitudinal Stability.—To obtain longitudinal stability it is necessary to balance the four forces which act upon an aëroplane through their respective centers, that is, gravity, lift, resistance and thrust. If these forces were to act always through a common point, it would be very easy to obtain and maintain equilibrium, but this is impossible in an aëroplane. While, by a suitable disposition of the various parts of the machine, we can fix the center of gravity, the center of resistance and the center of thrust, we can not always bring them in line, owing to constructional requirements, nor always count on the thrust, which varies with the varying power of the motor and will be completely absent when the motor is stopped and gravity supplies the gliding power; nor can we fix the center of lift, as it changes its position with a change in the angle of attack. The most we can do, therefore, is to balance these forces for the normal angle of incidence of the machine and introduce other means to restore the equilibrium when it is disturbed by a change of the angle or the stoppage of the motor. This is effected by additional horizontal and vertical planes placed at the rear of the main planes, which act either automatically or are controlled by the aviator. Let us suppose that the center of gravity of the machine A B (Fig. 12) is at G, and that, when in motion, the air will exert a center of pressure at P,

under the main plane A C. The force tends to lift the plane A C and to upset it. To avoid this, the horizontal plane D B is connected with the rear part of the machine, so that the same air pressure will act under it, and on account of

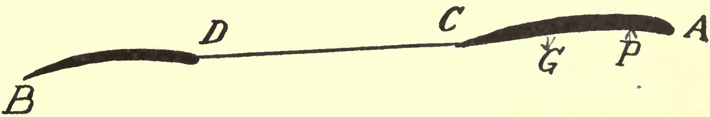


Fig. 12

its long lever arm C B, will counterbalance the force P and maintain the equilibrium of the machine.

If, instead, the aëroplane dives, due to a stoppage of the motor or other cause, the case is reversed; the main plane A C falls, while the plane D B rises and the air pressure acting on the upper side of the plane D B, forces it down and restores the equilibrium. Usually, this additional stationary plane is set at no angle of incidence and has just enough lift, due to the upper camber, to carry its own weight and that of the tail, so that it is very sensitive to any change of inclination.

To further supplement this righting force or direct the machine up or down, a horizontal rudder is provided, which is manipulated by the aviator by means of a control lever. By increasing or diminishing the angle of incidence of the horizontal rudder, which brings about a corresponding motion of the main planes, the machine is caused to rise or descend.

Lateral Stability.—To maintain lateral stability in straight horizontal flight, the best position of the center of gravity is below the center of pressure. In this way, if a side gust of wind strikes the aëroplane, compelling it to tilt, the center of gravity is displaced, too, from its normal position, which it will tend to regain and in so doing will bring the aëroplane back into equilibrium. But, evidently, this is only possible when the power of the wind is not so strong as to upset

completely the resistance opposed by the center of gravity. In the case of a strong wind, the aëroplane, struck sideways, would turn turtle.

In regard to the center of gravity below the center of pressure, it is to be observed that it must be neither too near to, nor too far from it. In the first case, the machine would be too sensitive to side motions; in the second case, there would be a swaying action which would tend to destroy rather than maintain equilibrium.

An additional means for maintaining lateral equilibrium is the warping of the planes or manipulation of the ailerons; that is, the lifting of the rear extremity of one of the main planes or wings and the contemporaneous lowering of the rear extremity of the other, so as to cause a difference in the angle of incidence of the two wings and bring about a twisting motion, in order to regain the lost stability.

Let us examine, now, the last phase of lateral stability, that is, circular flight.

When an aëroplane moves in a circle, it becomes subjected to a new force: the centrifugal force, which tends to drive the machine away from the center of rotation. As this force is directly proportional to the mass by the square of the velocity and inversely to the radius of the circle, it is greater, the greater the speed and the smaller the radius of the circle, and as the only side of the machine that offers resistance to the centrifugal force is the outer side, it is diverted from its course; but, on the other hand, the outer wing, describing a wider curve and traveling faster than the inner side, passes through more air and generates a greater pressure, with the result that the wing rises and tends to check the skidding tendency. This rising movement, though, must be regulated by the manipulation of the ailerons or the warping of the wings: by depressing one aileron and raising the other or warping the wings in an opposite sense for an amount proportional to the centrifugal force, the machine is made to take the curve with a lean to one side, just enough

to allow it to bank itself properly and counterbalance the effect of the new force caused by the turning motion.

The tilting of the aëroplane, and consequently of the air resistance, brings about a decrease in the lift and, therefore, the aëroplane will sag. The aviator must figure on this sagging motion before he starts to turn, to be sure to clear anything that might be below the machine.

This falling motion can not, of course, be avoided by increasing the speed, because both centrifugal force and air resistance are proportional to the square of the velocity; consequently, the higher the speed, the greater the centrifugal force and the bigger the degree of tilting necessary to overcome it, and, obviously, the greater the fall.

Having seen the effect of the new force on a machine in general, let us consider, now, the behavior of a machine having the center of gravity in a different position. There can be only three cases: center of gravity on a level with, above or below the center of pressure.

In the case of the center of gravity on a level with the center of pressure, if the machine is tilted just right, it will follow its right course without skidding; but if it is tilted too far, it will slide toward the center of the circle; and if tilted too little, it will skid to the outer side of the curve.

If the center of gravity is above the center of pressure, the turning movement is facilitated, because, in tilting the machine, the center of gravity, being high, will tend to cause the machine to fall, so to say, toward the center of the circle; but this tendency, being counterbalanced by the centrifugal force, will make the machine go perfectly around without skidding. With this position of the center of gravity, turning movements can be accomplished at a very high speed and, therefore, this is the best system for circling around.

When the center of gravity is below the center of pressure, on account of the tilting and the consequent decrease in lift, the center of gravity tends to restore the equilibrium

of the machine, and to bring the wings to a horizontal position again, which, of course, is against the turning motion requirement, and the machine tends to skid.

The conclusion to be derived from our analysis is that the best position of the center of gravity for straight horizontal flight is below the center of pressure, while the best position for turning is above the center of pressure, but as the latter is the worst of all to maintain equilibrium in straight flight, we can say that the best position of the center of gravity is below the center of pressure.

An aëronautical engineer, while admitting that for the present this is the best way, expresses the opinion that the future will see the center of gravity above the wings, because by that time the aëroplane will have acquired such a great rate of speed as to render it indifferent to atmospheric currents. But, considering the ever present menace of hurricanes, it is very doubtful that this will be the case, because, even admitting what he says in regard to speed, it is always possible that a slackening in the power of the motor, if not its complete stoppage, will cause it to diminish and then the aëroplane will be left at the mercy of the wind, which may force it to pay an unpleasant visit to Mother Earth.

Directional Stability.—As in the case of the longitudinal stability, the directional stability is obtained and controlled by means of additional stationary and movable planes. At the tail end of the machine, there are a stationary vertical stabilizer and a rudder. If the machine side slips or a gust of wind strikes it sideways, the pressure of the air will act on the vertical stabilizer, the tail will swing around, cause the nose of the machine to turn toward the direction of the side slip or wind and right its course.

The rudder, instead, is moved at the will of the aviator and caused to turn to the right or left, thus bringing about a corresponding motion in the machine and changing its direction.

Inherent Stability.—Analyzing the three different stabilities, we see that, aside from the balancing of the four forces acting on an aëroplane, they are obtained by means of additional planes, some of which are fixed and act automatically, and some others are movable and controlled by the aviator. This means that, without the controlling hand of a skilled and alert pilot, the machine would lose its balance at the first adverse condition. While, of course, it is possible to handle a machine of this kind, on the other hand, its operation is very tiresome to the operator, who can not fly for more than a few hours before he needs a rest, and this besides the fact that the controls operate only as long as the machine has forward speed, failing which, the aviator can not use them effectively. What we need, therefore, is a machine which acts automatically, approaching as much as possible the neutral equilibrium, and such an inherently stable machine is in existence to-day. Provided there is enough distance between a machine of this kind and the ground, to allow the righting forces to become operative, the machine can be thrown into any position, even upside down, and it will resume automatically its normal flying position. It is even possible for the aviator to fold his arms and allow the machine to fly itself. The only requirement in these cases is that the machine be at a fair altitude; so that we can assert, contrary to the popular belief, that in height there is safety. The disadvantages of an inherently stable machine are a slight loss of lift and sensitiveness of control, but they, of course, will never outweigh the all important factor of safety first, and after all, in this, as in any other case, a compromise is effected, by which the machine is built with a fair degree of both inherent stability and manual control.

Inherent stability in an aëroplane is attained by placing at angles its different planes, and these angles are: the longitudinal dihedral angle for inherent longitudinal stability; the lateral dihedral angle for inherent lateral stability and

the angle of sweepback for both inherent directional and longitudinal stability.

Longitudinal Dihedral Angle.—The longitudinal dihedral angle is the angle a (Fig. 13a) formed by the prolongation of the chord of a wing with that of the horizontal stabilizer of a machine, and it is made possible only by the decalage or difference in the angle of incidence between the wings and the horizontal stabilizer. The longitudinal dihedral angle is given to an aëroplane to maintain inherent longitudinal stability.

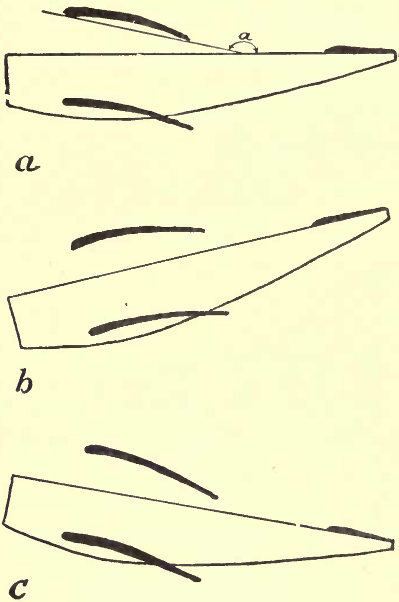


Fig. 13

Suppose that, while flying at its normal angle, the machine suddenly dives and assumes a tail-high position (Fig. 13b). In this case, as the momentum keeps the machine moving forward, the resistance of the air acts on the upper side of the horizontal stabilizer and sends the tail down, bringing the machine back to its normal position. If, instead, the tail drops (Fig. 13c), the case is reversed; that is, the air strikes the under side of the horizontal stabilizer and sends the tail up again.

The sensitiveness of the tail in restoring the longitudinal stability depends on the kind of horizontal stabilizer used, which makes the tail lifting, semilifting or non-lifting.

A lifting tail has for a horizontal stabilizer a lifting plane, with the usual upper convex camber and lower concave

camber (Fig. 14*a*), set at an angle of incidence smaller than that of the wings. While this has the advantage of lifting part of the weight of the machine, it has the disadvantage of not being sensitive in restoring the longitudinal stability, because when the angle of attack of an aëroplane changes and brings about a corresponding change in the angle of the horizontal stabilizer, although the latter gains or loses more incidence in proportion, being set at a smaller angle than the wings, it still retains an angle of incidence, and, consequently, has lift, which militates against sensitiveness. In other words, if the angle of incidence of the wings is 3° and that of the horizontal stabilizer 2°, and the aëroplane dives until the angle of attack of the wings becomes 2°, the angle of the horizontal stabilizer becomes 1°; in this way, the wings have lost $^1/_3$ of the angle, while the horizontal stabilizer has lost $^1/_2$, and the consequence is that the tail, having no more enough lift to carry its own weight, falls. If the case is reversed, that is, if the tail drops until the angle becomes 3°, that of the wings becomes 4°; in this case, the horizontal stabilizer has gained $^1/_2$ of its angle, while the wings have gained $^1/_3$, and, consequently, the tail, having more lift than normally needed, rises.

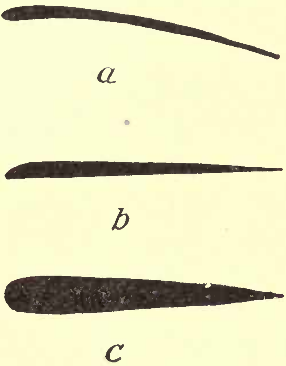


Fig. 14

A semilifting tail has a horizontal stabilizer with a slight upper camber alone, the lower side being flat (Fig. 14*b*), set at a zero angle of incidence. As the lift is just enough to carry the weight of the tail and the angle is zero, the slightest diving motion of the machine or dropping of the tail, setting the horizontal stabilizer at a negative or positive angle, produces a quick righting force, which restores the longitudinal stability. This arrangement constitutes a

happy medium of lift and sensitiveness and is in general use.

The non-lifting tail has a horizontal stabilizer with a convex camber on both sides (Fig. 14*c*), set at a zero angle of incidence. As the lift of one side neutralizes that of the other, being equal and opposite, and the angle is zero, this kind of horizontal stabilizer renders the tail the most sensitive of all, but the wings must carry the entire weight of the machine and its center of gravity must be far forward to balance the weight of the tail.

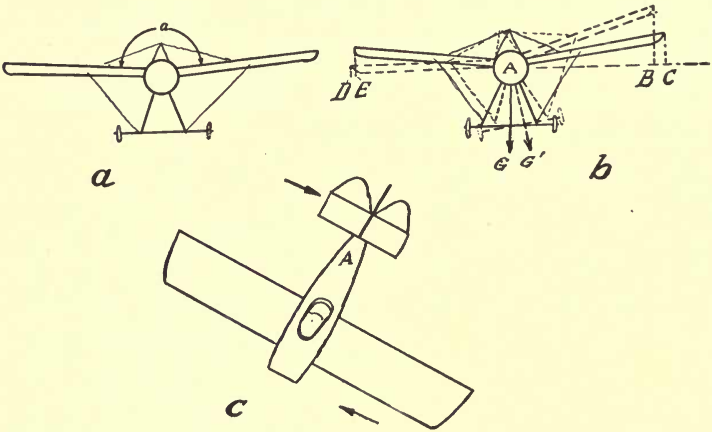


Fig. 15

Lateral Dihedral Angle.—The lateral dihedral angle is the angle a (Fig. 15a) formed by two wings when they are tipped upward and it is given to an aëroplane to obtain inherent lateral stability.

If a gust of wind strikes the machine sideways and sends one wing up and consequently the other down (Fig. 15b), the center of gravity G of the machine, being displaced, G', tends to regain its normal position and to bring the machine back to an even keel. In the meantime, the wing that is up

loses some of its lift, due to a smaller horizontal equivalent *A B* than before *A C*, and tends to drop, while the lower wing, having more lift caused by a greater horizontal equivalent *A D* than before *A E*, resists the dropping effect of the higher wing. The outcome is that the higher wing, being compelled to fall on account of both the displacement of the center of gravity and the diminution of lift, and being in the meantime resisted by the lower wing, side slips toward the direction of the lower wing. This side motion brings a pressure against the vertical stabilizer *A* (Fig. 15*c*), which causes the nose of the machine to swing around toward the direction of the slide; the higher wing, being on the outside of the curve, acquires more speed and climbs again, to fall back again and repeat the same oscillating motion, with a continuously diminishing intensity, until the equilibrium is finally restored.

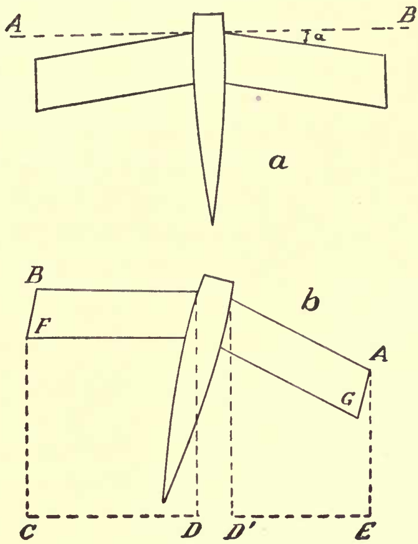


Fig. 16

The swinging motion of the machine is detrimental, but unavoidable, as is also the diminution of lift, due to the inclination of the wings, which have a smaller horizontal equivalent than they would have if they had no angle, but considering the benefit derived, it is better to have a lateral dihedral angle, even if some lift is lost.

The greater the angle, the greater would be the inherent lateral stability, but the smaller the lift, so that a compro-

mise is attained by setting the wings at a small angle, which combines a fair degree of stability and lift.

Angle of Sweepback.—The angle of sweepback is the angle *a* (Fig. 16*a*) formed by the leading edge of a wing with the lateral axis *A B* of an aëroplane. It gives both inherent directional and longitudinal stability to a machine.

If the aëroplane is diverted from its straight course, one of its wings *A* (Fig. 16*b*) assumes a more inclined position than the other *B*, and the air, offering a greater resistance against the wing *B*, which presents an equivalent surface *C D* greater than that *D′ E* of the other *A*, forces the more exposed wing *B* back and restores the directional stability.

If the machine dives, the air resistance acts on the upper sides *F* and *G* of the wing tips and forces up the nose; if, instead, the tail drops, the air acts on the under side of the wing tips and forces up the tail, thus restoring the longitudinal stability.

As the directional stability of a machine does not present much difficulty, besides the fact that the vertical stabilizer promotes it, and the longitudinal stability can be maintained by means of the longitudinal dihedral angle with less loss of lift than the sweepback entails, and also on account of difficulty of construction, the sweepback is not much used.

Vertical Stabilizer.—The inherent directional stability is maintained in almost all aëroplanes by means of the vertical stabilizer, which is a flat triangular plane bolted on the upper part of the tail.

If during flight a gust of wind strikes an aëroplane on one side *A* (Fig. 17*a*), the pressure, although acting on the entire aëroplane, produces more effect on the vertical stabilizer *B* on account of its long lever arm and causes it to swing to the opposite side *C* (Fig. 17*b*). As momentum tends to keep the aëroplane in its previous direction, the pressure of the air acts now on the other side of the vertical stabilizer and forces it back to its former position, thus righting the course of the aëroplane.

If the case is reversed, the same principle holds good.

Gliding Angle.—One of the most important points to consider, in connection with the inherent stability of an

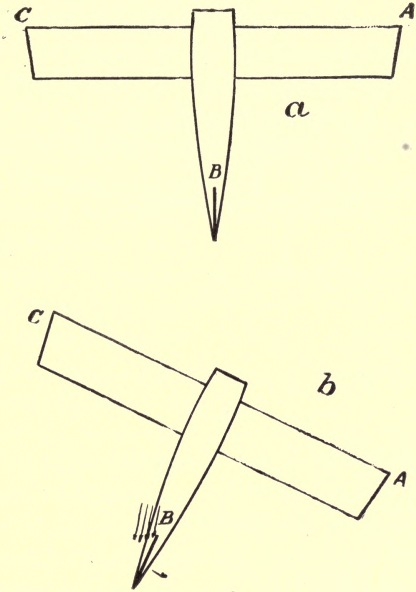


Fig. 17

aëroplane, is that when the motor is stopped and gravity furnishes the motive power.

It is clear that in this case the machine can do nothing but glide down, and to do so safely, it is imperative that it assume the proper gliding angle automatically. To this end, the four forces which act on an aëroplane are disposed so that the center of gravity G (Fig. 18) is a little in advance of the center of lift L, and the center of resistance R a little above the center of thrust T. Due to the disposition of the center of gravity ahead of the center of lift, the aëroplane would come down nose foremost, if no other force counter-

acted that of gravity; but when the motor is working, this opposing force is furnished by the thrust of the propeller,

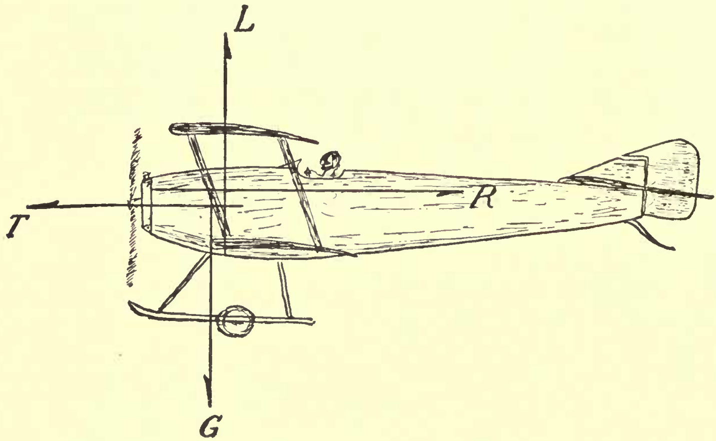


Fig. 18

and when it is stopped, the necessary force is supplied by the pressure of the air against the center of resistance, which, being above that of the thrust and far in advance of the center of gravity, resists the nose-diving tendency of the aëroplane to such an extent as to make it assume the proper gliding angle automatically.

The location of the point of application of each force, which determines the degree of the gliding angle *A B C* (Fig. 19) of an aëroplane, determines also, as a consequence, its radius of action *C B* or horizontal equivalent of the gliding path *A B*.

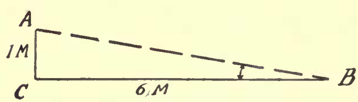


Fig. 19

The radius of glide is altered by the power of the wind, being increased or decreased according to the direction of the aëroplane in relation to that of the wind.

The gliding angle is usually expressed in terms of the ratio of the height of glide *A C* to the radius of glide *C B*;

that is, if the height from which an aëroplane starts to glide is 1 mile and the distance traveled in a straight horizonal line in reference to the ground is 6 miles, it is said that the gliding angle is 1 in 6.

As the radius of glide is directly proportional to the height of glide, we have here again the confirmation of the fact that height means safety, because it gives a greater radius of action and, therefore, affords the pilot a better opportunity to choose a suitable landing place.

Propeller Torque.—Among the different causes which affect the lateral stability of an aëroplane, one deserves special consideration: the propeller torque. This rotary force tends to produce an opposite rotary motion to the point of application, which, if free to move, will actually revolve, as is the case with the helicopter using only one propeller. If the propellers are two or any even number, the effect of the torque is eliminated by making one-half of them revolve in the opposite direction to the other half.

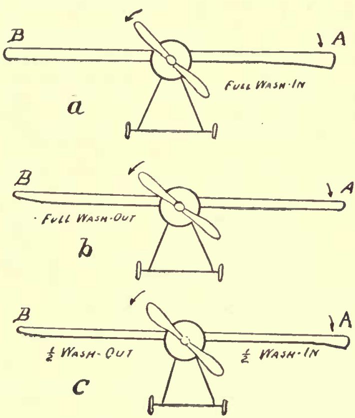


Fig. 20

In the case of a machine having one propeller, the result is that one wing A (Fig. 20a) is forced down, and, consequently, the other one, B, up. To correct this direct effect of the propeller torque, the angle of incidence near the tip of the lower wing is increased or washed in to a degree necessary to give it enough additional lift to bring the wing back to its normal position and restore the lateral stability. The same correction can be made by decreasing or washing out the angle near the tip of the high wing B (Fig. 20b) to bring it down to its proper level. A better system, though, is to

increase the angle on one side A (Fig. 20c) and decrease it on the other B by one-half the amount needed for the total increase or decrease. One reason why this method is to be preferred is that an increase in lift means also an increase in drift, which causes the wing with the bigger angle to retard its forward motion and to bring about a consequent turning movement in the machine, which will be greater, the greater the drift, and this, of course, is the case when the angle is increased or decreased all on one side. Another reason is that when the ailerons are used to restore the lateral stability by bringing one up and the other down, they do not work in air with the same density, because the lower aileron receives the compressed air from the lower camber, while the upper receives the rarefied air from the upper camber, and the consequence is that the lower aileron is more effective and introduces in the meantime more drift than the upper, with the result that the machine swings around towards the side of the lower aileron, and this makes necessary the operation of the rudder in conjunction with the ailerons to keep the straight course of the machine. The smaller the angle near the wing tips, the smaller the drift of the lower aileron, the smaller the turning tendency of the machine and the smaller the angle of the rudder. By dividing the angle equally between the wing tips, therefore, the amount of drift is reduced to the minimum and so the consequent turning motion, both in regard to that caused by the correction of the direct effect of the propeller torque and the other brought about by the manipulation of the ailerons.

To correct the indirect effect of the propeller torque, either the rudder or the vertical stabilizer is set at an angle toward the wing tip which has less incidence, thus introducing an equal amount of drift to that side of the machine and restoring the directional stability. As the torque of the propeller varies with the power of the motor, being completely absent when the motor is stopped, and is not therefore a fixed quantity, while the angle at the wing tip is, it

becomes necessary to correct by manipulation the variations in the stability of the machine, produced by the change in the torque. For this reason, it is better to use the rudder in correcting the indirect effect of the propeller torque, because the rudder can always be moved at will by the aviator, while the vertical stabilizer is bolted in place and once set, is set to stay.

CHAPTER II

AËROPLANE CONSTRUCTION

Parts

The main parts of a monoplane are four; those of a biplane may be four or five. We will consider the case of the biplane with five parts, which, when named in their assembling order, are the following: fuselage, undercarriage, center section, wings and empennage.

All these parts are light and strong structures produced by a skillful combination of wood, metal and fabric.

Fuselage.—The fuselage (Fig. 21) is the main body of the aëroplane, all other parts being attached to it.

The wooden parts of the fuselage are: the longerons, top A (Fig. 21a) and bottom B (Fig. 21b); the struts, top C (Fig. 21a), bottom D (Fig. 21b) and side E (Fig. 21c); the tail post F (Fig. 21c) and the engine rails G (Fig. 21a). The metallic parts are: the fittings H (Fig. 21c) with their rivets or clevis pins and cotter pins or bolts, nuts and cotter pins; the turnbuckles M (Fig. 21a); the cross bracing wires, top I (Fig. 21a), bottom J (Fig. 21b), side K (Fig. 21c) and internal L (Fig. 21d); the nose plate N (Fig. 21a); the engine rails support O (Fig. 21a); and the reënforcing struts P and Q (Fig. 21c).

At the tail end of the fuselage is the rudder post R (Fig. 21c) and on the under side is the tail skid S (Fig. 21c), which sometimes is attached to the rudder post and sometimes to an independent piece T (Fig. 21c).

The longerons are made of strong wood, as they must stand all kinds of stresses without breaking, because to change a damaged longeron means to dismantle the fuselage and, consequently, the entire machine.

The struts are lighter and weaker wood, intended to take only a compression stress.

The tail post is not used in all machines, as sometimes the rudder post has the double function of tail post and rudder post.

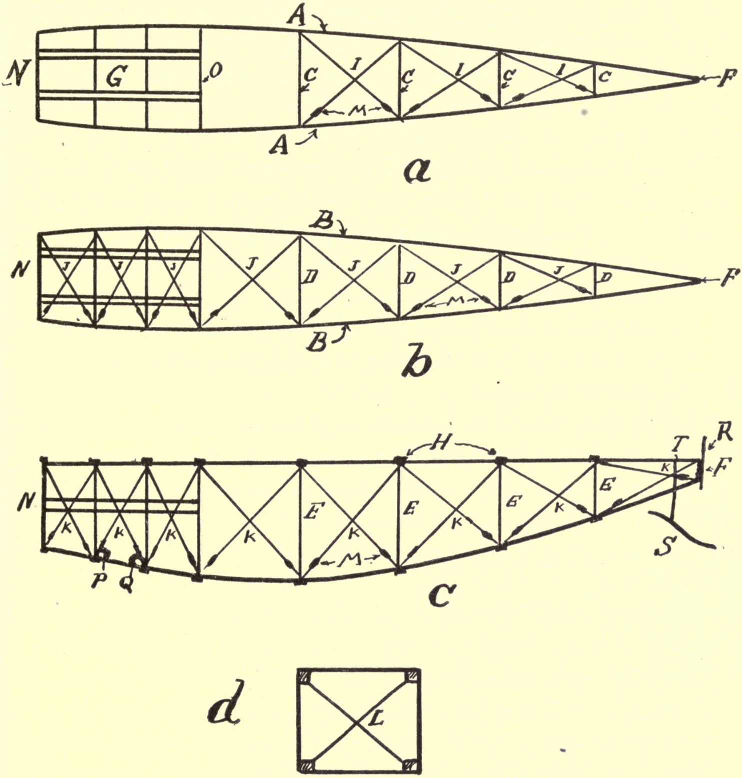


Fig. 21

The engine rails are very strong wood, usually laminated, and they are fixed in place in the strongest possible way, because on them is bolted the motor.

The fittings are metallic fixtures which connect the joints of the struts and longerons. The wires are also attached

to them by means of rivets, pins or bolts. The fittings and their fixtures are used in all the other parts of the machine and they will be omitted hereafter, unless meant for a special purpose.

The turnbuckles are couplings, with a barrel and a right and a left hand eye screw or shank, used to regulate the length and tension of wires. The right hand screw shank, which sometimes is split or forked, is generally attached to a fitting. This is done to determine the turning direction of the barrel in tightening or loosening a wire, as, in this case, the operation is that of an ordinary right hand screw nut. The come and go is the distance the shanks can be screwed in or out. The turnbuckles also are used for all the wires and they will be omitted in the descriptions of the other parts of the machine.

The cross bracing wires are of the greatest importance, as from them depends the rigidity and consequent strength of the entire machine.

The nose plate, engine rails support and the reënforcing struts are used to give the strength and rigidity required for the installations of the motor, whose vibrations might cause the loosening of some weak part and cause a disaster.

The rudder post is a metallic tube to which is hinged the rudder.

The tail skid is a strong piece of wood and is attached under the tail of a machine to carry the weight of its rear portion while on the ground and to act as a shock absorber and brake in landing. It is better to have the tail skid attached to an independent piece, rather than to the rudder post, because in case of a bad landing, the latter may be distorted so as to jam the rudder.

The main sections of the fuselage are: the engine section *A* (Fig. 22), the cockpit *B* and the tail section *C*.

The fuselage is covered all around with cowling or fairing to give it a stream-lined shape. This cowling is metal for the entire engine section and the upper part of the cockpit,

the balance being fabric, sometimes reënforced by a light framework of wood, and this is especially the case with the part that covers the tail section. The cowling of the top takes special names, according to the section it covers: hood

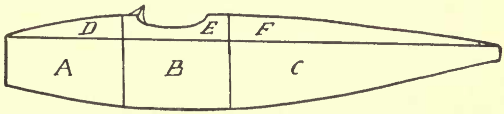


Fig. 22

D for the engine section, cowl *E* for the cockpit and turtle-back *F* for the tail section.

The fuselage is constructed in the strongest possible manner to withstand all kinds of stresses, and as the other main parts are attached to it, its fittings are so made that while they hold its own members together, they are ready to receive the other parts of the machine.

The fuselage is usually made in a square section, built box girder fashion and has a fineness of 7. Although stream-lined to diminish the passive drift as much as possible, this shape does not represent the last word in science, it being

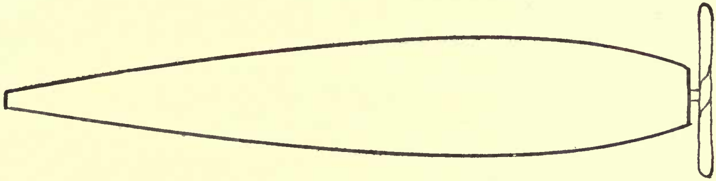


Fig. 23

well known that other experimental models have given much better results. The future will undoubtedly see the shape of the fuselage so altered as to give the least amount of drift.

There is a cigar-shaped fuselage (Fig. 23) specially constructed and covered all around with plywood, so as to form one single shell and for this reason is called monocoque, which in French means one shell.

Sometimes the common box girder type of fuselage is covered also with plywood, monocoque fashion.

There is another kind of short body or cut off fuselage called nacelle (Fig. 24), which is used for machines that have the propeller in the rear.

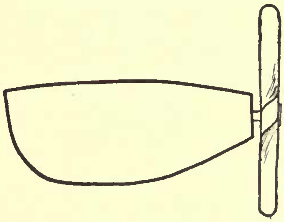


Fig. 24

Undercarriage.—The undercarriage (Fig. 25) is that part of the machine designed to support it when at rest, to absorb the shock of landing and to give clearance to the propeller and wings.

The wooden parts of the undercarriage are: the struts *A* (Fig. 25*a*) and the spreader *B;* the metallic parts: the cross bracing wires *C*, the axle *D*, the wheels *E*, the shock absorber fittings *F* (Fig. 25*b*) and the radius rods *G*.

Besides these, there are additional parts of rubber, that is, the tires for the wheels and the cables of rubber used as shock absorbers.

The struts of the undercarriage are made purposely weaker

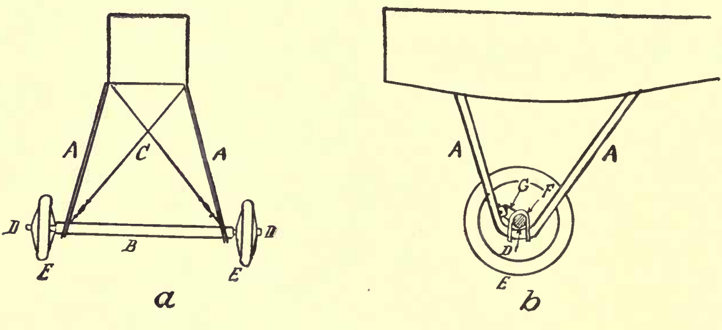


Fig. 25

than the longerons of the fuselage, so that in case of a hard landing, it will be the struts which will break, as they are easily replaced.

The spreader keeps the struts at the proper distance and is stream-lined to diminish the drift.

The wheels used for the undercarriage are the same as those for automobiles and they run up to 32 inches in diameter. The heavier the machine, the larger the wheels, but the standard size is 26 x 4, that is, a wheel of 26 inches and a tire of 4 inches diameter. The larger the diameter of the wheels and tires, the better suited to run on rough ground, but of course the weight compels the limitation of the size. The hubs of the wheels have no ball or roller bearings to be lighter, but the spokes are very substantial and well spread out to resist side stresses.

The tires are of the double tube type, that is, they have an air casing and a shoe or outer casing. The center of the shoe is harder, because it is the part that comes in direct contact with the ground and is called the thread. The pressure that a tire can stand is 20 pounds per sectional linear inch, but this pressure is never given, because the tire, besides being used to facilitate the run on the ground, must absorb some of the shock of landing. The spokes of the wheels are covered on both sides with disks of metal, canvas or celluloid to stream-line them, and in this case they are called disk wheels.

The shock absorbers used to-day are generally of rubber, in the form of a cable of strands of rubber covered with fabric, wound around the undercarriage fittings and the shock absorber fittings. It is important that the cables of both wheels have the same tension, to prevent a side motion of the machine in moving along the ground and particularly in landing, when it would be very dangerous and might cause the machine to turn over sideways. The strands of rubber run from 50 to 300 and the size of the cable from half an inch to one inch. The length of cable used is proportional to its diameter and the weight of the machine. These shock absorbers are preferred because they are readily adjusted and replaced, their deterioration is easily detected and they ab-

sorb much more than steel per unit weight. They are not ideal, though, because the more they stretch, the less they absorb, and a shock absorber should really absorb the shock of landing without giving a rebound. This could be obtained by the use of the hydraulic or oleo pneumatic shock absorbers. They consist of two tubes, one inside the other, separated by either water or oil; the outer tube is attached to the axle of the wheels and the inner tube to the undercarriage. When the machine is in flight, the weight of the wheels and axle pulls the outer cylinder down and the liquid flows all in the outer tube. When the machine lands, the inner tube presses the liquid and forces it inside of the inner tube through a valve at its bottom, and as it goes in, the air in the inner cylinder resists it, thus forming a cushion of air which absorbs the shock, while the liquid, through ports in the inner cylinder, is forced out and back again into the outer tube. As, after landing, the shock-absorbing power does not exist any more, and it is necessary to have some of it when the machine is pulled about on the ground, an additional spiral spring is provided, which comes into play when the inner cylinder reaches the limit of its downward run. The liquid is generally oil, because it is less liable to freeze than water. Although these are real shock absorbers, they are not used much on account of their weight, complication of parts and high cost.

A kind of shock absorber, which is a combination of shock absorber and wheel, is the Ackerman wheel, whose spokes are S shaped for the purpose of absorbing the shock of landing.

An important point to be observed in regard to the use of the rubber shock absorbers and the Ackerman wheel is that in the first case the rubber cable is wound around the undercarriage fittings and the shock-absorber fittings, which means that when the machine lands, the axle must give and stretch the rubber; while the axle of the Ackerman wheels must be rigidly attached to the undercarriage, as in this case it is the spokes that absorb the shock.

The radius rods are guides pivoted to the axle and the struts, to prevent the possibility of the axle striking and breaking the struts when the machine lands and the wheels and axle jump up.

Some machines have neither radius rods nor separate shock-absorber fittings, in which case there is a special axle fitting, which is a combination of all these parts in one.

The undercarriage deserves a good amount of thought to avoid damage both to the aviator and the machine even before they leave the ground. The weight of the machine rests on the undercarriage, therefore it must be strong enough to withstand the stress of its load when at rest, more so when moving, because of the increased stress imposed by the shocks imparted by the runs on an uneven ground, and in the greatest degree when landing.

The undercarriage should be so built as to give a quick start and a quick stop. Evidently these are opposite requirements, because if a machine must start quickly, it means that the wheels must give the least amount of friction and, for this very reason, the machine can not stop quickly. To accomplish both results, it is necessary to have a brake, which will stop the machine at the proper time in landing. This mechanical brake would be a very good addition to an undercarriage, because often it happens that a machine lands on slanting ground and the aviator has no means of stopping it to avoid a smashup; but, on the other hand, the brake requires a proper adjustment to avoid the tendency of the machine to come down on its nose when the brake is applied.

The undercarriage should be well sprung and strong enough to withstand rolling and side shocks without deflection or fracture, and it should also offer the lowest drift when in flight, which means that all its parts must be stream-lined and so disposed as to take full advantage of the shielding effect.

The height of the undercarriage depends upon the diameter of the propeller, which should have a clearance of from one

to two feet to prevent breakage due to the tilting of the machine or to the sinking of the wheels into soft ground.

The center of gravity of the machine is usually very near the center of the wheels, and therefore the tail section of the fuselage and the skid are built lightly. If the center of gravity is too far back, it is necessary to have a heavy fuselage and skid, which, in landing, cause a heavy drop of the tail and a consequent increase of the angle of incidence of the wings, and the result is that the machine rebounds. A heavy fuselage means greater frictional resistance for the skid, which prevents a rapid start.

If the machine has a lifting tail, the tail end of the fuselage and the tail skid can be built much lighter than when the tail is non-lifting.

Center Section.—The center section (Fig. 26) is the central structure which connects the upper wings of a multiplane.

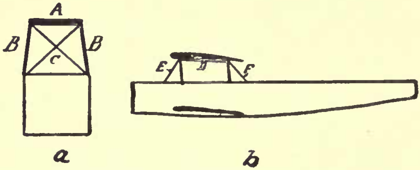


Fig. 26

The principal part of the center section is the panel *A*, which is a section of wing and the part always missing in a monoplane and sometimes in a biplane. The reason is this: the monoplane has only one set of wings and they are fixed directly to the fuselage; the biplane, instead, being provided with two sets of wings, has the lower ones attached to the fuselage as in a monoplane, while the upper wings are attached to the center section, in which case the main parts will be five; or they are united end to end by means of fittings and supported by struts, and then there is no center section, in which case the parts of a biplane are also four as in a monoplane.

The wooden parts of the center section are the struts *B*, and the metallic parts: the cross bracing wires *C*, the bracing wires *D* (Fig. 26*b*), the drift wires *E* and the antidrift wires *F*.

The cross bracing wires of the center section are found usually in the front and the rear, the bracing wires taking the place of the cross bracing wires, which should be on the sides also. These side cross bracing wires are eliminated and substituted by the bracing wires, because the seat of the aviator is almost always inside of the center section and, consequently, the sides must be free from obstructions, so that he can go in and out.

The drift wires have the object of strengthening the center section against the pressure of the air when the machine is

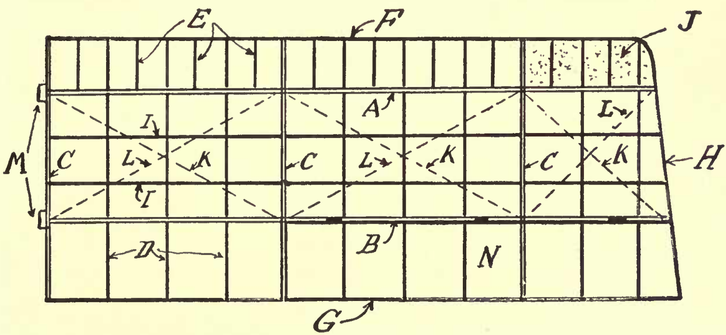


Fig. 27

in flight, and the antidrift wires are necessary to counteract the tension of the drift wires and to keep the center section straight and rigid.

Wings.—The wings (Fig. 27) are the lifting members of the machine, whose entire weight hangs from them, and therefore they must be built very strongly.

The wooden parts of the wings are: the spars, front *A* and rear *B;* the compression ribs *C*, the camber ribs *D* and the false ribs *E;* the leading edge *F* and the trailing edge *G;* the wing tip *H;* the stringers *I* and the three-ply veneer *J*. The metallic parts are: the drift wires *K*, the antidrift wires *L* and the hinges or fittings *M*.

The wings are covered with fabric, which is made tight by coating it with a special solution.

The compression ribs are solid and are used for strength, while the camber ribs are lightly built and their purpose is to give the proper shape to the fabric. The false ribs are merely strips of wood, which run from the leading edge to the front spar and they are used to prevent the fabric from sinking between the ribs proper. Sometimes, instead of the false ribs, the three-ply veneer is used, and sometimes, both false ribs and three-ply are found in the same wing.

A rib is made of three parts: a web *A* (Fig. 28) and two cap strips *B* and *C*. The web or center part is made in three pieces, leaving two openings for the spars.

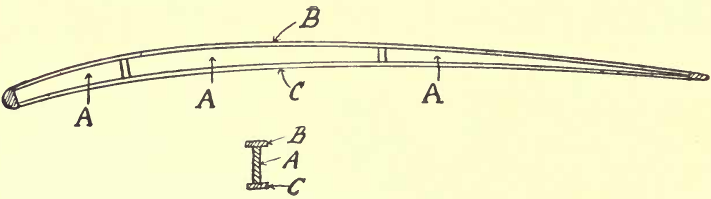


Fig. 28

The stringers are long strips of wood running through the webs of the ribs to keep them from rolling over. Sometimes, these pieces are round and they are called dowels.

Generally, a wing is cut toward the rear edge so as to form a rectangular plane *N*, which constitutes a part by itself and is hinged to the wing; this is the aileron. Sometimes, the part where the aileron should be is not cut off, but is made flexible, so that it can be warped up or down, and this is especially the case with the monoplane.

The ailerons are used to control the lateral stability of a machine and to bank it properly during a turn.

Empennage.—The empennage (Fig. 29) is the tail of the machine.

The parts of the empennage are: the horizontal stabilizer *A*, the vertical stabilizer *B*, the elevators *C* and the rudder *D*.

All these parts are constructed in the same way as the wings, that is, they consist of a framework of wood, braced by wires and covered with coated fabric.

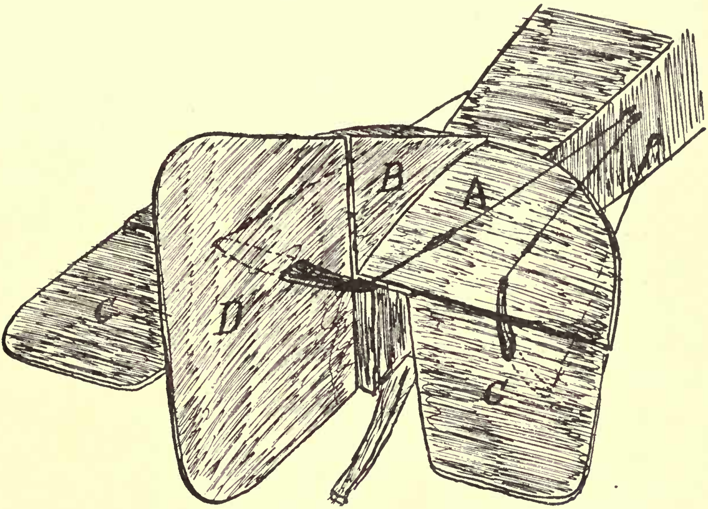


Fig. 29

The horizontal stabilizer maintains inherent longitudinal stability and the vertical stabilizer inherent directional stability.

The elevators are used to make a machine climb or descend and the rudder to make it turn to the right or left.

Wires.—When the wings of an aëroplane are mounted, they are held rigidly in place by means of additional wires, struts and metallic tubing.

In a monoplane, these additional bracings are: the cabane *A* (Fig. 30*a*), which is a metallic framework built on the upper part of the fuselage; the landing wires *B*, which run from the top of the cabane to the upper part of the wings and hold them when the machine is on land; the flying wires *C*, which run from the undercarriage to the lower part of the wings and hold them when the machine is in flight; and the

drift wires *D* (Fig. 30*b*), which run from the nose plate to the wings and hold them against the drift during flight.

The cabane is a necessity in a monoplane, because if the landing wires were attached directly to the fuselage, they

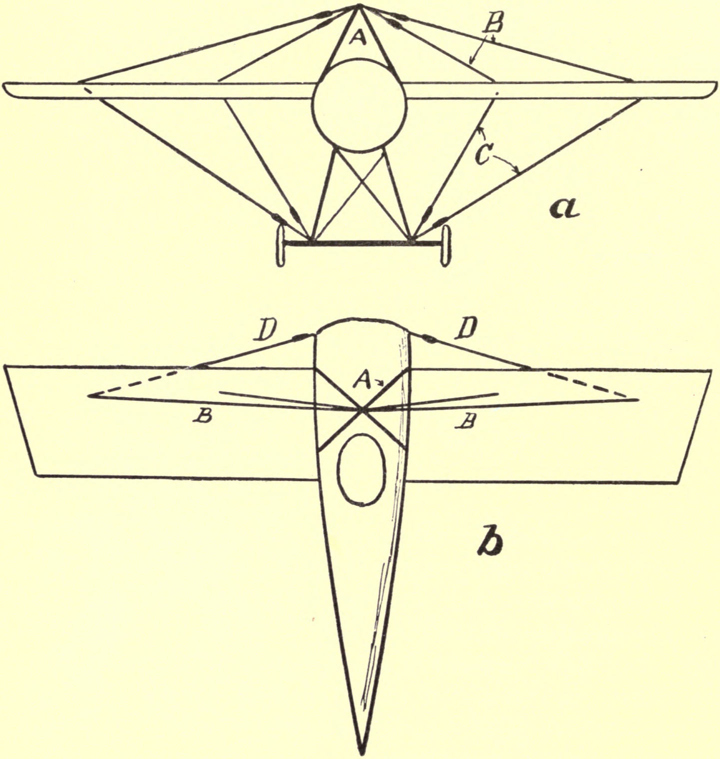


Fig. 30

would be too low and would hardly have any bracing strength. Even attached as they are, these wires, and also the flying wires, do not give much strength to the wings, running to them at a slant, and, consequently, the monoplane is weak in construction, although very efficient in regard to lift.

In a biplane or multiplane, the additional bracings are:

the interplane struts *A* (Fig. 31*a*), which hold the wings apart; the landing wires *B;* the flying wires *C;* the stagger and incidence wires *D* (Fig. 31*b*), which brace the wings one

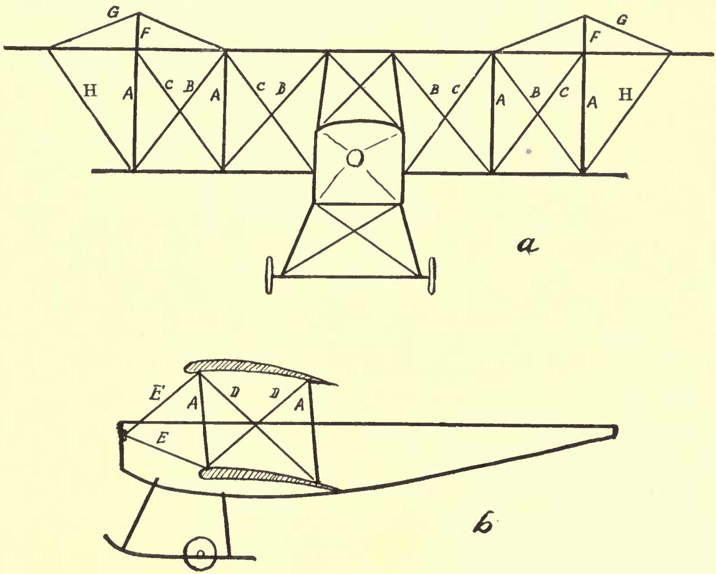


Fig. 31

with the other; and the drift wires *E*, which run from the nose plate to the wings.

Such a box girder bracing makes the biplane very strong in construction, but it detracts from its lift, increasing the passive drift and causing interference in the gap. For parity of surface, the lift of the biplane is about 85 per cent that of the monoplane.

When a biplane has an extension, further bracings are used to strengthen it. These are: the king-post *F* (Fig. 31*a*), the bracing wires *G*, which serve as landing wires, and the flying wires *H*.

The landing wires usually are single, being sufficient to

carry the weight of the wings when the machine is on the ground and to stand the additional stresses of normal and abnormal landings. The flying wires, instead, are double, because they must carry the entire weight of the machine and stand all the abnormal stresses imposed by the different positions assumed by it in flight. The important fact must not be overlooked, however, that sometimes the landing wires are subjected to the abnormal stresses produced by a reversal of loading, which equal, if indeed they do not surpass, those of the flying wires. This takes place in such cases as steep gliding, upside down flying and rolling, when the weight of the machine is borne in part or in full by the top of the wings and transmitted to the landing wires. For these performances, a machine must have double landing wires.

Power Plant.—A very important part entering in the construction of an aëroplane is the power plant, which to-day is the four-stroke gasoline motor, being the lightest and most powerful invented so far, although it has the great inconveniences of high speed, vibrations and noise.

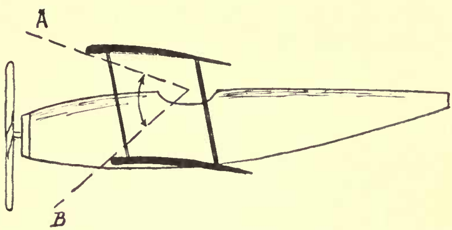


Fig. 32

The position and number of motors give different names to an aëroplane: if the motor is in front, the aëroplane is a tractor; if in the rear, a pusher; and if the motors are two, a twin-motor aëroplane, either tractor or pusher.

The tractor aëroplane (Fig. 32) has the disadvantage of a limited range of vision *A B*, because, on account of the motor in front, the aviator has to sit in the rear part of the machine to balance it, and the wings limit his visual radius; but, on the other hand, it is less dangerous for the aviator in case of a fall, because the motor is in front and can not drop on him.

The pusher (Fig. 33) has an unlimited range of vision, because the aviator sits in the front part of the machine, but in case of a fall, the motor may drop on him and crush him to death. Another great disadvantage of the pusher aëroplane is that it needs outriggers *A* to give clearance to the propeller. The outriggers increase the weight and drift, due to their size, position and necessary bracing with struts and wires. It was just on account of this awkward construction that the propeller was tried in front, although all authorities agreed that for efficiency its best position was in the rear, but when the first trial was made, a most astounding result was obtained: the lift was more than doubled. This is due to the fact that the relative speed of the air is increased by being thrown back by the propeller against the machine. It is true that the passive drift is increased, also, and more power is needed to overcome it, but on the other hand, the surface of the wings can be cut down, making it possible to shorten the span and increase the strength of the wings, which is a very great advantage, especially in the case of a monoplane.

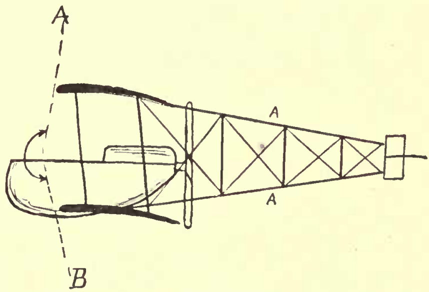


Fig. 33

Controls

The controls are mechanical devices used to operate the controlling planes, that is, the ailerons, the elevators and the rudder.

The controls in use to-day are two: the wheel control, called also Deperdussin or Dep, and the stick control. In both mechanisms, the hands are used to operate the ailerons and

elevators, which require finer motions, and the feet for operating the rudder.

The wheel control (Fig. 34) consists of a hand wheel *A* (Fig. 34*a*), a drum *B*, a control column *C*, two pulleys *D* and a wire *E*. The wheel is pivoted to the upper end of the control column and is free to turn to the right and left, while the other end *F* of the control column is pivoted to the bottom of the cockpit and can be moved only in a fore and aft direction. The center of the wire is attached to the drum at one point and then is wound around a spiral groove cut in the side of the drum, so that if the wheel is turned to the right, the left end of the wire is pulled and the right end released; and vice versa. To the right end of this wire is turnbuckled a control wire *G*, which after passing around a pulley, runs to the under side of the right aileron *H*, and to the left end another wire *I*, which goes to the under side of the left aileron *J*.

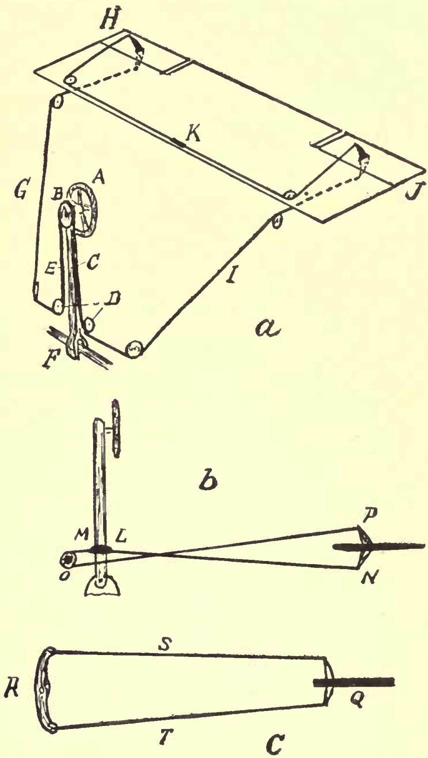


Fig. 34

On the upper side of the wing with the ailerons, which in a biplane is usually the top wing alone, is a balance wire *K*,

whose right and left end is attached to the upper side of the right and left aileron respectively, so that if one is lowered, the other one is raised, and vice versa. At the center of the balance wire is a turnbuckle, which is used to regulate the position of the ailerons in regard to the wings. All these wires are attached to masts, which are bolted to the control planes.

With such an arrangement, a turn of the wheel to the right brings down the left aileron and up the right one, and a left turn of the wheel reverses the motions.

On the front side of the control column is attached one pair of wires *L* (Fig. 34*b*), above the pivot point, and on the rear side, opposite the first pair, is another one *M*. The front pair runs to the lower side *N* of the elevators, the right wire being attached to the right elevator and the left to the left; the rear pair, after passing around pulleys *O*, goes to the top side *P* of the elevators and the two wires are attached similarly. The wires, therefore, cross one another, so that a forward motion of the wheel or control column pulls down the elevators, and a backward motion brings them up.

The rudder *Q* (Fig. 34*c*) is controlled by a foot rudder bar *R*, pivoted in the center, and two wires, one *S* attached to the right and the other *T* to the left end of the bar, which run to the right and left side of the rudder respectively. Thus, a push to the right or left end of the bar pulls the rudder to the right or left.

The wheel, therefore, operates the ailerons; the column, the elevators; and the foot rudder bar, the rudder.

This control is in a neutral position when the wheel is so turned that the point of attachment of the wire on the drum is on the top; the control column vertical and the foot rudder bar at right angles with the longitudinal axis of the aëroplane.

Holding the control in neutral position, the aviator is enabled to operate the controlling planes easily and, with the exception of the rudder, naturally. If, for instance, the

left wing dips down, the aviator instinctively shifts his body to the right to keep his balance and, in so doing, he carries the motion of the wheel to the right; this brings down the left aileron and up the right. The resistance of the air, acting against the lower side of the lower aileron, pushes the lower wing up, while the resistance against the upper side of the upper aileron pushes the higher wing down, thus reëstablishing the equilibrium. If the case is reversed, the same principle holds good. If the aviator wants to come down, he pushes the wheel down, the elevators go down, and the air, acting against the lower side of the elevators, pushes the tail up and, consequently, the nose down; when he wants to go up, he pulls the wheel up and the motion is reversed. If he wants to turn to the right or left, he pushes the foot rudder bar to the right or left.

While the motion of the rudder seems natural, the right push of the foot corresponding to the right turn of the machine and the left to the left, it is not, and we are not used to this system of conrol. If we ride a bicycle, when we push the right side of the handle bar, we turn to the left, and vice versa. The same should be with the foot rudder bar and it could easily be accomplished by simply crossing the wires. Why this is not done is probably due to the fact that the aviators, having mastered this awkward motion, are not prone to change it, fearing that, through force of habit, they may encounter with some accident in making an involuntary inverse motion when they are in a dangerous position, and so they teach the same system to their pupils, continuing the same erroneous motions.

The stick control (Fig. 35) consists of a vertical metallic tube or stick A, a horizontal tube B, two arms C and two bearings D. The stick is forked at one end E and is pivoted to the horizontal tube so as to form a universal joint, which makes it possible to move the stick from side to side without moving the horizontal tube and to turn the latter in its bearings when the stick is pushed forward or pulled back-

ward; the arms are fixed to the ends of the horizontal bar; and the bearings fastened to the floor of the cockpit. To the stick are fastened two wires, one to the right F and the other to the left side G, which run to the right and left aileron respectively, and to each arm are attached two wires, one at each end, the top wires H (Fig. 35*b*) going to the bottom of the elevators and the bottom wires I running to the top of the elevators; these wires, therefore, cross one another.

With this mechanism, a side motion of the stick operates the ailerons and a fore and aft motion operates the elevators. The rudder system is the same as in the wheel control.

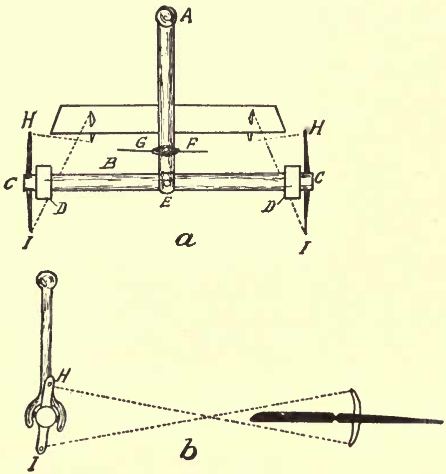


Fig. 35

While the mechanisms as described here are not used in all machines, the changes are only means to an end, the principle being always the same.

In biplanes having ailerons in both sets of wings, the control wire runs along the lower wings and the motions from the lower to the upper ailerons are transmitted by two compensating wires or struts, one connecting the right and the other the left ailerons together. With the use of compensating struts, there is no need of balance wire, because a strut can be used both to pull and push, while a wire can only pull.

Some machines have a dual control, the two units being

connected by additional wires and bars in such a manner as to make their motions synchronous.

The wheel control is slow in its movements and is used for slow speed and training machines, while the stick control is operated quickly and is found in speedy machines flown by experienced aviators. The stick can be manipulated with one hand and some pilots have gone so far as to operate it with their knees, thus leaving both hands free, and as the stick is round and may slip from between the knees, a half round pad is attached on each side to fit the legs and permit a good hold on the stick. This is a very good improvement in war machines, enabling the pilot to have his hands free to operate the gun.

Pontoons

A special aëroplane part found only in water machines or hydroaëorplanes is the pontoon (Fig. 36), which is a flat

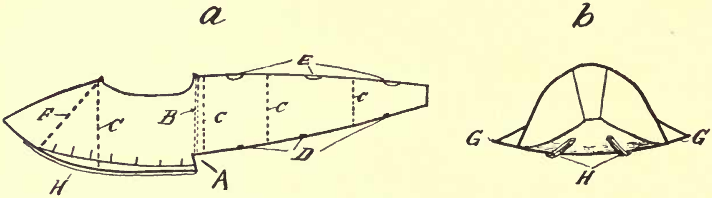


Fig. 36

bottomed, air-tight, boat-like float attached to a land machine to enable it to rest on and rise from the water, skimming on its surface like a hydroplane.

A pontoon is usually built with ply-wood, alternated with painted canvas, glued with marine glue to a thickness of about one-quarter of an inch and closely screwed to a framework similar to that of a boat.

In a pontoon, we find: the step *A* (Fig. 36*a*), the vent pipes *B*, the bulkheads *C*, the drain holes *D*, the hand holes

E, the reënforcing struts *F*, the planing fins *G* (Fig. 36*b*) and the battens *H*.

The step is a very important feature of the pontoon and its object is to facilitate the rise of the machine by breaking the hold of the water from the bottom of the pontoon. When the machine starts to skim, the inclined bottom of the forward part of the pontoon presses the water down and makes it acquire a downward trend, which, on account of the adhesion of the water to the pontoon, pulls it down. As the step is reached, the hold of the downward current is broken from the bottom and is carried to the water behind the step. This water, being pulled downward, causes a vacuum behind the step, with the result that the pontoon can not leave the water easily, if the formation of the vacuum is not prevented and this is exactly the function of the vent pipes. Being always open to the air, they keep it in constant contact with the water at the step and avoid the formation of the vacuum. The diameter of these pipes when first used was about half an inch, while now it has reached two and one-half inches.

The bulkheads divide the pontoon in compartments to prevent it from sinking in case of a leak, confining the incoming water to one section only.

The drain holes serve to drain out the water which may be found in the pontoon when the machine is beached. The drain holes are closed by plugs.

The hand holes are used to bail out the water while the machine is floating, to sponge any remains after it has been drained and to ventilate the pontoon when the machine is on land. The hand holes normally are closed by covers.

The reënforcing struts strengthen the pontoon against the shock of landing, both in a vertical and inclined direction.

The planing fins increase the planing surface of the pontoon. The minimum surface should be one square foot for each 500 pounds of weight, but in actuality is much more than that.

The battens are attached to the bottom of the pontoon to avoid damaging it when the machine is beached.

The manner in which the pontoon is attached to a machine gives it a different name. Although all water machines

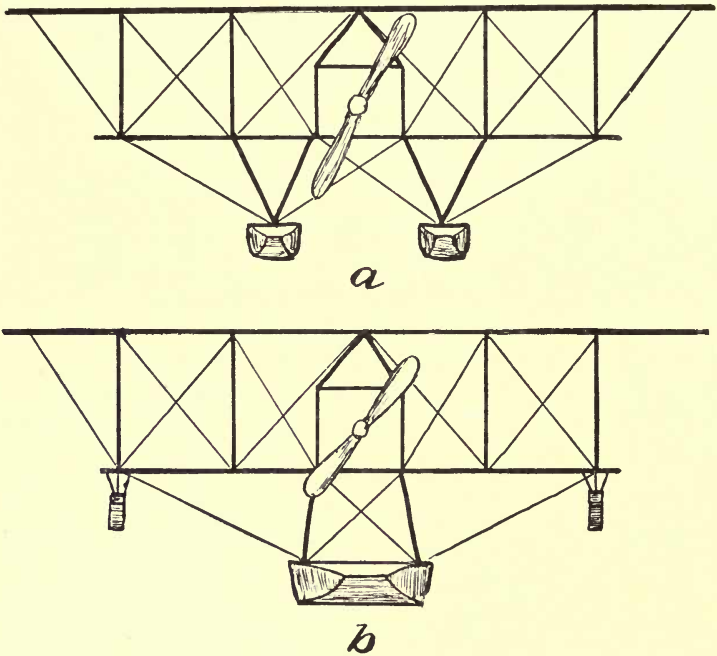


Fig. 37

are hydroaëroplanes, this term is used to designate an aëroplane which has an undercarriage with one or two pontoons attached to it (Fig. 37). A machine which has a pontoon in the place of a fuselage is called a flying boat (Fig. 38).

In regard to the number of pontoons used in a hydroaëroplane, it is to be noted that while two pontoons give a better support to the machine on the water, on the other hand they increase the drift when the machine is in flight, because for equal volume they offer more surface than one

pontoon. Then, too, they subject the machine to heavy stresses in a rough sea, because while one pontoon is on the crest of a wave, the other is down in the trough, and this see-sawing motion is dangerous. One pontoon causes no

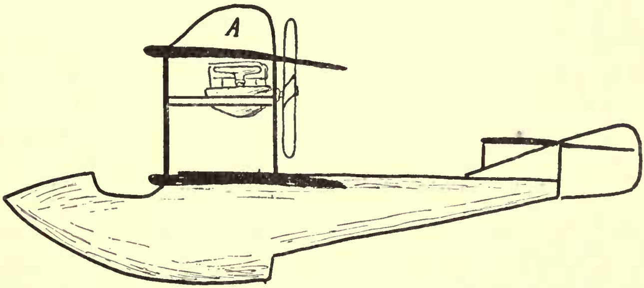


Fig. 38

stresses and gives less drift, but is not so steady and requires the use of additional small floats at the wing tips and sometimes at the tail (Fig. 37*b*).

Pontoons offer a great amount of lateral or keel surface, which renders a water machine very sensitive to side winds and also causes it to skid in a turning motion. To offset this tendency, an extra plane or non-skid fin *A* (Fig. 38) is attached to the top of the wings, which, on account of its long lever arm, counterbalances the pressure against the side of the pontoons.

Materials

A successful aëroplane must be the combination of strength, lightness, rigidity and flexibility; but to combine all these opposite requirements into one single structure, in order to render it indifferent to all kinds of stresses, is perhaps the most difficult problem man ever undertook to solve, which calls into duty almost every known branch of industry and commands the employment of first class skill and material.

That a machine should be strong, it goes without saying, as it must stand the pressure of the air, the vibrations of the motor and the shocks in starting and landing; that it should be light, it is a capital requirement to accomplish flight; and rigid it must be as a whole to withstand distortion, but up to a certain degree, when flexibility comes in to avoid undue stiffness of the parts, which might break if stressed out of proportion; and that these are *sine qua non* conditions to obtain a perfect flying machine, nothing can attest more than the long, painstaking work of the great American pioneer, Professor Langley, whose noteworthy perseverance only could bring the hard task to completion.

To solve the difficult problem in the best possible way, the materials used to-day in constructing an aëroplane are: wood, metal and fabric, variously combined; although the all-metal machine, which has already made its appearance, will undoubtedly be the machine of the future.

Before we examine in detail these materials, it is necessary that we know something about their strength and the terms used in connection with it.

Strength of Materials.—Stress is the load to which a body is subjected and it is expressed in pounds per square inch.

Stresses are simple and compound; the simple are: compression, tension and shear stress; the compound: bending and torsion.

Compression is the stress which tends to crush a body.

Tension is the stress which tends to elongate a body.

Shear stress is the stress that tends to tear a body in such a manner as to cause one part to slide over the other.

Bending is the combination of the compression and tension stresses.

Torsion is a combination of the compression, tension and sheer stresses.

The bending stress has a special importance in aëroplane construction. When a body is bent, its molecules on the outside curvature are under tension, while in the inside they

are under compression and in the center none of the two stresses is felt and there is, therefore, a neutral line. This enables us to hollow the parts used in aëroplanes, thus saving about 33 per cent in the weight of material.

All bodies have a limit beyond which they can not be stressed without collapsing and being permanently deformed. Strain is the deformation produced by an over stress.

Factor of safety is the ratio of the stress of collapse of a body to the maximum stress it is called upon to withstand. If, for instance, a body can stand a stress of 1000 pounds and it is used to stand only 100, its factor of safety is 10, that is, $1000 : 100 = 10$.

The determination of the factor of safety is a matter of great controversy among aëroplane designers, some choosing a factor of safety of 6 and others going as far as making it 15. Every designer gives apparently good reasons for the factor of safety adopted, but what really decides the question is the actual test, and while it is true that some machines can withstand successfully all kinds of over stresses, it is not less true that often they have been burdened with unnecessary weight. On the other hand, while machines built with a rather low factor of safety have given good account of themselves in the majority of adverse conditions, in some cases they have collapsed. This was due to the fact that the machines were built to stand the most common cases of abnormal stresses, leaving out of consideration the exceptional ones. Evidently, this is not a good assumption, because the fact that they do not occur frequently is no excuse for their exclusion.

The calculation of the factor of safety is based on the case of a machine in horizontal flight in calm weather, in which case the load supported by the wings is normal and equal to the weight of the machine, excluding the wings, whose weight is directly distributed over the pressure surface and thus they form the support for the rest of the machine. With this as a basis, are then calculated the greater stresses

due to the various atmospheric disturbances and to the evolutions, which a machine is called upon to perform.

The air is very far from being a smooth and evenly flowing element; it contains gusts, eddies and upward and downward trends, which constantly assail a machine from all directions and against which the designer must provide, as he must also provide for the abnormal stresses brought about by banking, looping and flattening out, all of which impose upon the machine loadings considerably in excess of the normal.

Another case to be considered in figuring the factor of safety is the reversal of loading or top loading, when the load of the wings is reversed in direction and exceeds that of normal flight.

A machine built with a reasonable margin of safety will remain sufficiently under control even if some small structural part breaks during flight and will allow the aviator enough time to land without a smash.

Everything considered, it would seem that a factor of safety of 10 is well suited to provide for all eventualities.

Wood.—Wood is a very unreliable material, its strength varying considerably with the age of the tree, the season when it was felled, the geographical situation, the manner of seasoning, that is, if natural or artificial, and the different artificial method and size of the pieces used when seasoned. For this reason, the factor of safety of wood is about double that of metal.

Wood has great tensile strength and generally is more flexible than steel tubing, but one of the chief obstacles in the use of wood is the difficulty of finding it in sufficient lengths without any blemishes; then it becomes necessary to join the good pieces together in laminations, that is, to glue strips of wood alternating the joints. The glue in this case must be insoluble, otherwise the strips will fall apart through dampness. A special kind of lamination is the ply-wood, which is made with very thin sheets or plies of wood

glued together with the grain of one ply running across that of the other, thus forming a light, tough sheet.

The woods most used in aëroplanes are: spruce, ash, white pine, cedar, walnut, mahogany and oak.

Ash is a heavy wood, but it is also very strong and able to stand all stresses. Spruce is lighter than ash, but it stands only the stress of compression, and if bent or twisted, it splits easily. White pine is very light and does not split. Cedar is usually employed in the construction of pontoons, being well able to stand the action of water; mahogany is also used for pontoons, but it is very expensive. Walnut, mahogany and oak are generally used for propellers; the best of the three being mahogany, as it is the lightest and has the greatest tensile strength.

Each kind of wood is used according to its peculiar behavior in regard to flexibility, strength, lightness or hardness, but in aëroplane construction, the same kind of wood is not always used for the same part and, consequently, only general rules can be given.

The spars are usually made of ash, spruce or an ash-spruce combination, and they are hollow at the neutral axis, but solid where the compression ribs, struts and wires are attached.

The ribs are of spruce or of a combination of spruce for the cap strips and ash three-ply for the webs.

The leading and trailing edges are spruce, although metal is more commonly used for the latter.

The struts are generally spruce.

The longerons and skids are ash.

The engine rails are ash or laminated ash and spruce.

No matter what the kind of wood used, as a general rule, the parts of an aëroplane which must stand a greater stress than others are made of stronger, harder and heavier wood. For this reason, the engine rails, which must carry the weight of the motor and stand its vibrations, must be made of very strong wood. The longerons, also, must be made of strong

wood, able to stand all stresses without breaking, because, as we have already seen, a damaged longeron means the taking apart of the fuselage and, as a consequence, of the whole machine.

Metal.—The metal mostly used is steel, and that this is the best metal there is no doubt, as it withstands successfully all kinds of stresses.

The main reasons against the use of steel are: its weight, its liability to rust, the difficulty of obtaining the point of union of the component parts as strong as the components, and the fact that steel tubing, as generally used in aëroplane construction, while giving great rigidity, does not permit of great flexibility, as in a thin tube all the material is at the surface, far from the neutral center, and if bent, it breaks right through. For these reasons, wood has been generally preferred, but the modern tendency is toward its elimination, due to the introduction of non-rusting steel alloys, improved welding processes and more accurate calculation of the strength of the parts. The introduction of chrome nickel steel has increased the possibility of all metal constructions, which possess greater strength and homogeneity and permit the standardization of the parts.

Another non-rusting alloy which is now being tried, and, it seems, with good results, is the Monel metal, which is an alloy of 60 parts of nickel, 35 of copper and 5 of iron.

As the metal which on account of its lightness is the first to be thought of by the aëroplane builder is aluminum, a comparison between aluminum and steel is not out of place. While the specific gravity of aluminum is about one-third that of steel, its tensile strength is about one-sixth, so that in reality we ought to use six times an amount of aluminum to have the same tensile strength of steel, which consequently would double the weight of the material and increase the size of the parts, causing more passive drift. Then again aluminum is not very cohesive and its bending strength is very bad, a fact which forbids its use, especially when

it must be subjected to vibrations. In conclusion, out of the comparison, steel is the winner.

In aëroplanes, as built to-day, the metal used is mostly steel in the form of wires, fittings and seamless tubing; and of such additional accessories as turnbuckles, ferrules, thimbles, fair leads, bolts, nuts, washers, rivets, clevis pins, cotter pins, tacks, screws and metallic sheets, in whose manufacture other metals are also employed.

The wires are solid and stranded. Solid wire is used in parts of the machine which are not dismantled, because a solid wire can hardly be handled without kinking it and a kink means a weak spot, which, if strained, will break. The stranded wire is of three kinds: strand stay, which consists of from 7 to 19 wires stranded together; cord stay, which is made with 7 strands of from 7 to 19 wires to each strand; and control cable, which consists of 6 strands of 7 wires each and a cotton center. The strand stay and cord stay are used in all parts of the machine which must be handled in assembling, disassembling and adjusting, because they are flexible and can easily be coiled without kinking them. The control cable is used for the controlling planes, as it is very flexible and can easily go around pulleys.

The fittings are made of pressed steel and are used to connect all the parts of the machine and for the attachment of the wires.

Seamless steel tubing is employed for edges of controlling planes, for rudder and skid posts, for axles, struts and reenforcements.

Turnbuckles are usually made with two kinds of material: the barrel is bronze and the shanks steel. A turnbuckle (Fig. 39) is an important little device, which must be handled with care, because it is not so strong as it looks. First of all, pliers must never be applied to it, as the barrel is hollow and may easily be distorted or even cracked without showing any outside sign. If it is distorted, the threads will be spoiled and the shanks will not work freely, and if cracked, it may

snap while the machine is in flight and cause a disaster. The proper way to operate a turnbuckle is to insert a stiff wire or nail in the hole of the barrel and another in the eye of the shank connected to the wire to avoid it from turning.

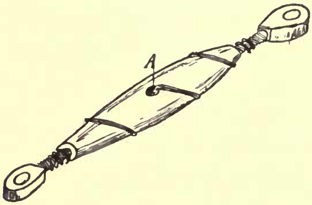


Fig. 39

Whenever a turnbuckle is unscrewed to disconnect a wire, the barrel must be screwed to the shank attached to the wire for a distance sufficient to avoid its occasional unscrewing and loss. When the wire is to be connected again, the barrel must be unscrewed all the way out, then screwed to the shank attached to the fitting just enough to catch it, the other shank brought to the other end and then the barrel turned, thus taking in both shanks evenly. If this rule is not observed, one of the shanks will be all the way in the barrel, coming to the end of its run, while the other shank is almost all out, and this will prevent the proper adjustment of wires which are cut the right length to be properly tensioned by the turnbuckles.

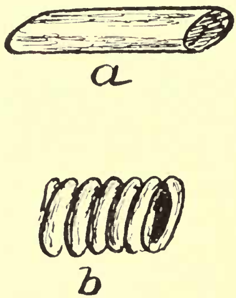


Fig. 40

After a wire has been adjusted, the turnbuckle must be locked to avoid it from turning. This is done by inserting a wire *A* in the hole of the barrel, winding both ends around the barrel in a sense opposite to its unscrewing direction, passing the ends through the eyes of the shanks and winding them on the shanks.

Fig. 41

The ferrules are of two kinds: solid and wire. A solid ferrule (Fig. 40*a*) is a short tube, usually of copper, flattened enough to make it oval. A wire ferrule (Fig. 40*b*) is made

with a wire coiled in a spiral and flattened to become oval. These ferrules are used in connection with the looping of a solid wire.

A thimble (Fig. 41) is an almond-shaped steel eye used in the inside of a stranded wire loop, to protect it from the wear caused by the friction of the shank.

A loop is the doubling of a wire in such a manner as to form an eye for the reception of a turnbuckle shank or the pin or rivet of a fitting.

Fig. 42

With a solid wire, only one kind of loop can be made, that is, the ferrule and loop (Fig. 42), which is fastened by means of a ferrule and by bending the end of the wire.

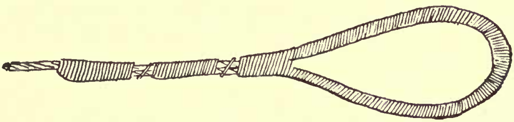


Fig. 43

With a stranded wire, three kinds of loops can be made: the wrapped and soldered loop, the thimble and loop wrapped and soldered and the spliced loop. The wrapped and soldered loop (Fig. 43) is made by winding fine copper wire around

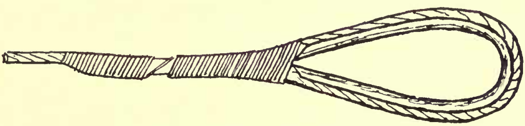


Fig. 44

the stranded wire at the part where it is to be looped, to protect it from wearing, doubling it, continuing to wrap both the wire and its doubled end and soldering the entire loop. The thimble and loop wrapped and soldered is made by inserting a thimble in the loop (Fig. 44), wrapping its

end with copper wire and soldering loop and thimble. The spliced loop (Fig. 45) is made in a way similar to the thimble and loop, with the difference that the end of the wire, instead of being soldered, is unwound and its component strands

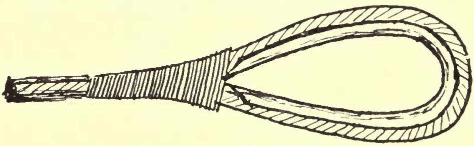


Fig. 45

inserted repeatedly in the wire and, finally, served with a fine string or wire for further protection.

Of the loops made with a stranded wire, the spliced loop is to be preferred for the absence of solder, because the soldering process requires the employment of acid, which filters into the wire and in due time will corrode it, causing it to break when the least expected and bringing about accidents. The spliced loop weakens the wire at the end of the splice, due to its kinking in splicing, but this loop will at all times give a warning of its weak condition and can be replaced in time to avoid damage.

Fair lead (Fig. 46) is a short copper tube with the ends enlarged funnel-like to prevent its edges from cutting and is used for the passage and guide of control cables.

Fig. 46

The bolts used in aëroplanes have a hole at the point (Fig. 47*a*) for the introduction of a locking cotter pin; the nuts are usually castellated (Fig. 47*b*), that is, they have grooves at their upper face to receive a cotter pin; the washers (Fig. 47*c*) are disks with a hole in the center for the passage of a bolt; the rivets (Fig. 47*d*) are short bolts without thread, used to lock parts together by burring the edge of the point; clevis pins (Fig. 47*e*) are rivets with a hole at the point for the passage of a cotter pin; the cotter pins (Fig. 47*f*)

are split keys made by bending a half round wire with the flat face inside, so as to form an eye at the bend and bring together the two halves or leaves, which thus make a round wire open in the middle, and they are used in holes of clevis

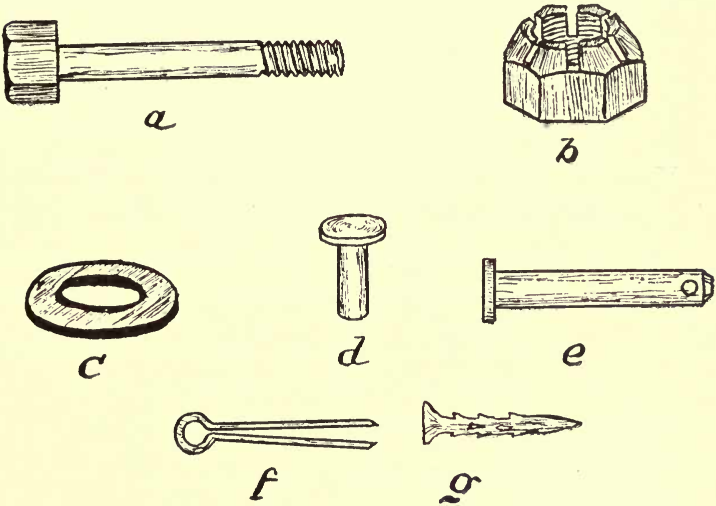


Fig. 47

pins to lock them by spreading out the leaves or to lock the nuts of bolts provided with an opposite hole at the threaded end. All these parts are made of steel.

The tacks, usually barbed (Fig. 47*g*), and the screws are copper or brass and are used to fasten fabric on wood or wooden parts together.

Metallic sheets of aluminum or galvanized tin are usually employed for stream-lining purposes.

Fabric.—The best fabric used for covering the planes is unbleached Irish linen, because the thread of the flax, which is used to make it, is about two feet long and thus provides a good overlapping margin when it is spun, forming a very strong cloth. It is left in its natural color to be stronger,

because the bleaching chemicals weaken the fabric. Irish linen weighs about 4 ounces per square yard and stands a load of over 60 pounds per linear inch of warp. Sometimes cotton, silk or a combination of both is used for plane covering, as cotton alone does not make a strong fabric, its threads being very short, and silk, although light and very long threaded, has the fault of absorbing moisture, besides being very expensive. Sea Island cotton is also used with good results, its thread being about as long as that of Irish linen.

There are two methods in use for covering the wings with fabric. One consists in throwing a large sheet of cloth on the frame, tacking it temporarily on one edge, passing the cloth around, tacking it permanently in place at all the edges and ribs and sewing it around the ribs. The other method is to be preferred, because it is easier and gives better results. It consists in cutting the fabric in the shape of the wing, sewing the edges around and turning it inside out, forming a kind of a bag, in which the frame is slipped and the mouth of the bag tacked permanently at the root end of the wing. The fabric is then tacked with as few tacks as possible on the under camber of the ribs. The wing is stood on the leading edge, additional strips of fabric laid on both sides of the ribs and both strips and fabric sewed around the ribs with about four loops of thread, which are repeated at a distance of a couple of inches. This gives the proper shape to the fabric, but does not make it very tight and to accomplish this result, it is painted with dope, and then an extra strip of cloth doped on each side of the ribs to cover the stitches.

Dope is cellulose nitrate or acetate dissolved in banana oil. Cellulose nitrate is the same compound of guncotton and is therefore highly inflammable, while the acetate is less inflammable. Banana oil is a mixture of acetone and amylacetate with liquid celluloid. As the vapor of the solvent is inflammable and volatile, care should be taken not to have an open fire in close vicinity of the dope container

and not to leave it uncovered or the dope will thicken, due to the evaporation of the solvent. Dope will thicken also at a low temperature. If the thickening is due to evaporation, the dope can be brought to its normal flow by adding the right amount of solvent, but if caused by the temperature, it is only necessary to warm it for a short time by putting the container in some warm place.

The brushes used for the dope must be kept immersed in it or they will stiffen, in which case it is necessary to stand them in it until they become soft again.

If the fabric to be doped, as well as the brushes and dope cans, are not clean, dry and free from oil or grease, the dope will not adhere well and will peel off when dry. Fabric soiled with greasy matter can be easily cleaned by rubbing it with a piece of cloth moistened with gasoline or acetone.

In doping new fabric, the first coat is applied with a light pressure on the brush to cause the dope to filter through, but all successive coats must be applied lightly and quickly without brushing out as is usual with paint, otherwise the previous coatings will be cut. Every coat must be dry and scraped with steel wool to even up the dope before the next coat is applied. Four coats of dope are required to make the fabric very tight and airproof. To render the dope less inflammable and make it waterproof, two coats of spar varnish are given.

Spar varnish is a dense, but clear and easy flowing, yellow liquid, which dries quickly with a lasting luster. It is the best kind of varnish for exterior work, being waterproof, elastic, durable and able to stand the effects of grease, oil, rain, hot and cold, fresh or salt water, extreme or sudden variation of temperature, without cracking or changing its color, and for these reasons, it is used on boats as a protective coating for wood, metal and fabric.

A change of color in a varnish is a sign of deterioration, because it then becomes porous and allows the harmful elements to filter through and attack the materials which it is intended to protect.

CHAPTER III

RIGGING

Assembling

Fuselage.—To assemble a machine, the first thing to do is to place the fuselage in the position necessary to attach to it all the other main parts. To this effect, the tail skid is connected by pinning it to the socket of the tail post or independent skid post and tying the shock absorber. The front part of the fuselage is then lifted on a wooden horse high enough to allow the undercarriage to be fitted to it. In lifting the fuselage, care must be taken not to damage it, and if block and tackle is used, the hook of the block must be attached to a line passed under the engine rails.

Undercarriage.—After mounting the wheels on the axle, the undercarriage is pushed under the engine section of the fuselage until the fittings correspond to the struts, which are put in place and bolted. The cross bracing wires are then connected and the fuselage tail is raised and supported on a horse, so as to assume the rigging position. The shock absorbers are wrapped in place and tied.

Center Section.—The center section struts are bolted in their sockets on the fuselage, the panel mounted and bolted to the struts, and the cross bracing wires and drift and anti-drift wires attached in place.

Wings.—The ailerons are removed to prevent any possible damage and facilitate the work, and the wings assembled in pairs by standing them on the leading edges, which must rest on cloth or cushions to avoid damaging the fabric on the nose of the wings. The two wings are spaced apart the proper distance, the front and rear struts bolted in their

sockets, the stagger and incidence wires attached first, to prevent the wings from wabbling, and then the front and rear flying and landing wires are connected to make the structure rigid. The wings are now lifted bodily and connected to the center section by means of the top and bottom hinges and pins and the inner landing and flying wires. The first pair of wings must be supported by a horse placed directly under the outer struts until the second pair is connected. The ailerons are then mounted by means of the hinges and pins.

Great care must be taken in handling the wings to avoid damage and they must never be lifted by taking hold of the struts or trailing edges. The best way is to lift them by means of wooden boards, placing blocks between the boards and the spars, which thus carry the load.

The top pins are put in place first, because they are enough to hold the wings and in the meantime facilitate the introduction of the lower pins. The front struts and flying and landing wires are attached before the rear ones to make the work easier, as the latter would be in the way, if they were put in place first.

In dismantling the wings, the mounting process is reversed, by starting to detach first the part that was attached last.

To facilitate the assembling of the wings and prevent errors in mounting, the struts are numbered, and although the system varies with different manufacturers, the numbers are always painted on the inside part of the struts, to enable the aviator to see them from his seat and easily detect any error of position or inversion.

As a general rule, when a part has been assembled, the nuts of the bolts are screwed tight, cotter pinned and the leaves of the pins spread backward. The hinge pins are also cotter pinned in the same way.

When possible, the bolts are put in place with the point downward, so that if a nut should come loose, the bolt would

not fall; although this must not be an excuse for carelessness on the part of the rigger to omit the pinning of the bolts. Whenever the position of a bolt is not vertical or inclined, so that this rule can not be followed, then the nut is placed on the inside, to be easily seen by the aviator from his seat.

Empennage.—The horizontal stabilizer is bolted in place and the bracing wires or struts attached on both sides. The vertical stabilizer is bolted on the horizontal stabilizer and the bracing wires attached on both sides. The rudder is mounted on the rudder post by means of the hinges and hinge pins. The elevators are connected with the horizontal stabilizer in the same way as the rudder.

Control Wires.—The control wires of the ailerons, elevators and rudder are connected by means of the turnbuckles.

Truing

In truing up an aëroplane, the basis of all adjustments is the manipulation of the cross bracing and opposite wires, that is, the slackening of one and the tightening of the other to properly reshape parts thrown out of true.

To facilitate the work, the angles are measured in inches instead of in degrees, as they ought to be measured.

The right and left side of an aëroplane and the clockwise and anticlockwise revolution of a propeller are determined by the position of the aviator sitting in the machine.

The following rules for truing up an aëroplane are intended for field shop work, which is quite different from that done in the factory, where the rigger has at his disposal all the necessary equipment and tools to obtain the best results in the least time.

Fuselage.—To true up an aëroplane, the first thing to do is to place the fuselage in the rigging position (Fig. 48), which is done by leveling the engine rails longitudinally and laterally, as they are the basis of the alignment of all parts. To accomplish this, a horse is placed under the fuselage,

immediately in the rear of the engine section, so that the center of gravity of the fuselage will be toward its rear and the tail will have a tendency to fall to the ground. While the tail is being supported temporarily, a chain is tied to the

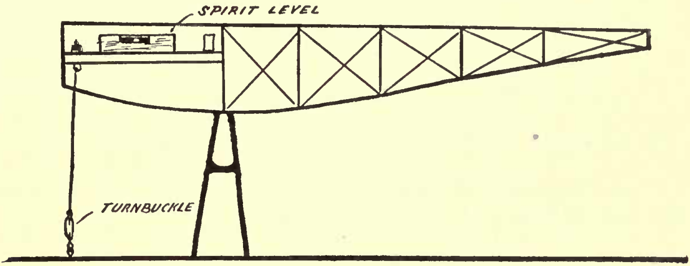


Fig. 48

nose plate and to an eye fixed to the floor. This will keep the fuselage in place with the tail sticking out unsupported. To facilitate the work, the chain has a turnbuckle to raise and lower the fuselage any desired amount. A level is now placed laterally on both engine rails and the fuselage leveled crosswise by inserting a wooden wedge between the fuselage and the top rail of the horse at the side which needs to be raised. This done, the level is placed longitudinally on one of the engine rails and the fuselage leveled lengthwise, moving it up or down by means of the turnbuckle. The level is then placed on the other engine rail, which, if it is true, should also be level; if it is not, it must be adjusted by means of the side cross bracing wires of the engine section, loosening one and tightening the other the necessary amount. Then, the centers of the bottom struts of the engine section are marked, a line stretched from the center of the first to that of the last strut and the bottom cross bracing wires manipulated until the line cuts all center marks. The next thing is to level the fuselage from the rear of the engine section to the tail. To do this, all the internal cross bracing wires must first be slackened, otherwise they bind the manipulation of

the other wires; then both longerons are leveled longitudinally by sighting them and correcting roughly by eye any up and down distortions by manipulating the cross bracing wires, after which the level is placed longitudinally on the longerons to straighten them out properly by the use of the same wires.

To correct any sidewise distortion, the top and bottom cross bracing wires are used respectively. This work is done by measuring and marking the centers of all top and bottom struts and stretching lines from the centers of the last top and bottom struts of the engine section to the rudder post, and adjusting the top and bottom cross bracing wires until the lines cut all the center marks on the struts.

The internal cross bracing wires are now tightened, while the level is placed transversally on the longerons to avoid throwing them out of level in tightening the wires improperly.

The above rules hold true with a machine having the line of thrust parallel with the top longerons; if this is not the case, special rules must be furnished by the manufacturer.

The assumption has also been made that the motor is not in place on its bed; if it is, then the level must be placed on any available part of the engine rails, and, if it need be, even held against their bottom.

Undercarriage.—In case of a new machine, the front and rear cross bracing wires must be manipulated until they have the same length and tension. With an old machine, this system can not be applied, as the fittings may be distorted or the heads of the bolts sunk unevenly into the wood, and the length of the wires may not be the same, although the undercarriage may be aligned.

A method applicable to all machines is to mark the center of the fuselage at a point directly above the axle of the wheels and the center of the axle or the spreader (Fig. 49), then to drop a plumb line from the upper mark and adjust the cross bracing wires until the point of the bob is over the center of the axle. If there is no part available on the fuselage to

mark its center, a yard stick may be laid on the longerons and the center taken from there.

Center Section.—The center section is trued up in a way similar to that of the undercarriage, that is, by marking the centers of the leading and trailing edges or front and rear spars of the center section panel and the centers of the struts below them on the fuselage or by using yard sticks in the absence of struts (Fig. 50*a*). The center section is then aligned by manipulating the front and rear cross bracing wires until the points of the bobs of the plumb lines dropped from the upper center marks are directly above the lower ones.

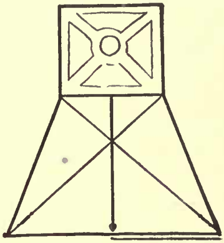


Fig. 49

If the machine has a stagger, a plumb line is dropped from the leading edge of the center section panel in front of each strut (Fig. 50*b*) and the measurements taken in front of the bottom sockets of the same struts, adjusting the drift and antidrift wires until the proper distances are obtained.

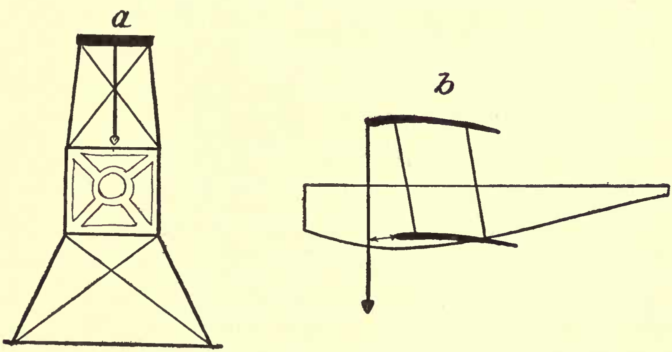


Fig. 50

Wings.—Leading edge. To make any adjustment in the wings, the first thing to do is to slacken the stagger and incidence wires, otherwise they bind the manipulation of

the other wires. This done, the leading edges of the wings are aligned by standing on a ladder some distance away from the machine, sighting along the leading edge of each top wing separately and straightening it by means of the front landing and flying wires of the outer bay. The manipulation of these wires straightens also the leading edges of the lower wings.

When a machine has an overhang, its wires must be used too in the straightening process.

After the wings are straightened, they must be brought in line with the leading edge of the center section panel by manipulating the landing and flying wires of the inner bay.

The reason why the outer bay wires are used to straighten the wings is because one end of each wire is attached to the

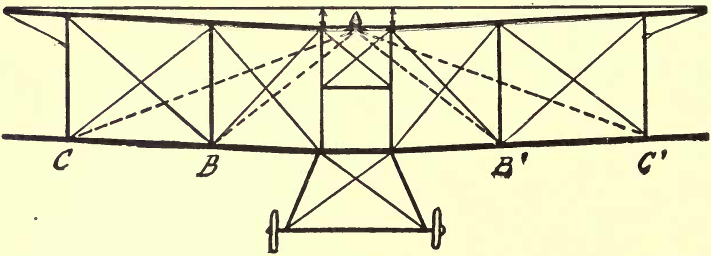


Fig. 51

spar of the upper wing and the other end to the spar of the lower wing between struts, thus bracing the rectangular framework formed by the spars and struts and rendering possible their adjustment; while only one end of each wire of the inner bay is fixed to the spar, the other being fastened to the center section or the fuselage, making possible only the raising or lowering of the wings. In the entire straightening and aligning process, only front wires are used, because the rear are manipulated to set the angle of incidence.

Lateral Dihedral Angle.—To set the lateral dihedral angle, one end of a line is tied to the outer front strut of one wing

(Fig. 51), then passed over both wings along the front spar, stretched enough to avoid sagging and tied to the outer front strut of the other wing. The measurement is taken from the line to both sides of the center section panel, and the landing and flying wires of the inner bay are manipulated until the proper distance is obtained.

Care must be taken to measure from both sides of the center section, because if the distance is measured at the center, the dihedral angle may be set wrong, as the wings may not have been raised equally on both sides and while one is higher than the other, the center may give the proper distance.

The hidedral angle may be checked by taking measurements from the center of the leading edge of the center section panel to equal points on both sides of the wings; for instance, from that center mark A to the lower sockets of the inner struts B, B', or the outer struts C, C'. If the dihedral is right, each pair of distances must be equal, $A\,B = A\,B'$, $A\,C = A\,C'$.

Angle of Incidence.—The angle of incidence is checked at the root end of the wings and measured under each set of struts by placing against the center of the rear spar one end of a straight edge (Fig. 52), leveling it out and measuring vertically from the center of the front spar to the top of the straight edge. The proper distance can be given by manipulating the rear flying and landing wires. The front landing and flying wires must not be touched, as this would throw off the adjustment of the wings, both in regard to straightness and alignment with the center section panel or dihedral angle, if any.

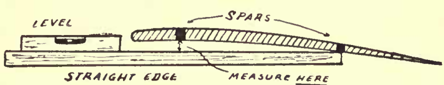


Fig. 52

The angle of incidence is never measured from the trailing edge or between the struts, as the possible warping of these parts may give a wrong measurement.

Stagger.—The stagger is set by dropping plumb lines from the leading edges of the upper wings in front of each strut (Fig. 53) and making the distance specified equal throughout, by measuring from the lower edges to the plumb lines and manipulating the stagger and incidence wires accordingly.

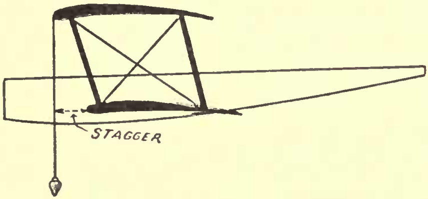


Fig. 53

Care must be taken in determining whether the specified distance is to be measured along the chord or a horizontal distance straight out, as this causes a difference which is enough to unbalance a machine.

Wash in and wash out.—To correct the direct effect of the propeller torque, the angle of incidence is changed usually at the wing tip under the rear outer strut, but in some machines it is tapered down from the tip to the root of the wing by adjusting the angle under both rear struts.

Aileron Droop.—The ailerons are drooped by lengthening the balance wire and taking the required measurement from the bottom of the rear edge of the wing to the bottom of the rear edge of each aileron. The droop is given for the reason that when the machine is in flight, the pressure of the air under the ailerons takes up the slack and brings them in line with the wings.

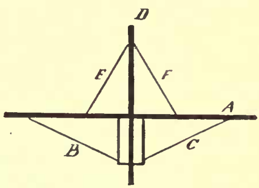


Fig. 54

Empennage.—The horizontal stabilizer *A* (Fig. 54) must be in a horizontal position, which is determined by bolting it in place properly and adjusting its side bracing wires *B* and *C*.

The vertical stabilizer *D* (Fig. 54) is aligned by adjusting its side bracing wires *E* and *F* until it is vertical.

With the control column in its neutral position, the control cables are adjusted until the elevators A (Fig. 55) are on a line with the horizontal stabilizer B, using for this a straight edge C under them both or sighting them.

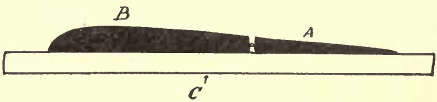


Fig. 55

With the foot rudder bar in its neutral position, the control wires are adjusted until the rudder A (Fig. 56) is at right angles with the rear edge of the horizontal stabilizer B.

The rules regarding the rudder and elevators do not take into consideration the correction of the indirect effect of the propeller torque, nor the drooping of the elevators; if these adjustments must be made, the following process is available:

If the propeller torque is corrected by means of the vertical stabilizer A (Fig. 57), the rigger has nothing to do with it, its mere bolting in place giving the necessary position.

To set the rudder at an angle to the right A (Fig. 58) or

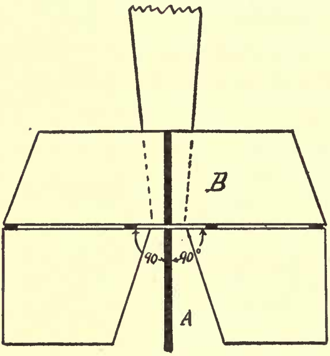


Fig. 56

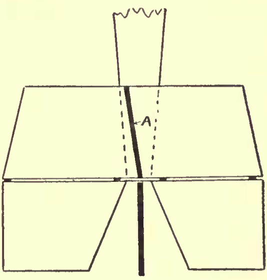


Fig. 57

left, a line B C is stretched from the vertical stabilizer D to the rudder and, keeping the foot rudder bar neutral, the control cables are so adjusted as to make one so much shorter

than the other that the rudder will form an angle *a* with the line, the given distance being measured from the rear edge of the rudder to the line. A straight edge may be used instead of a line.

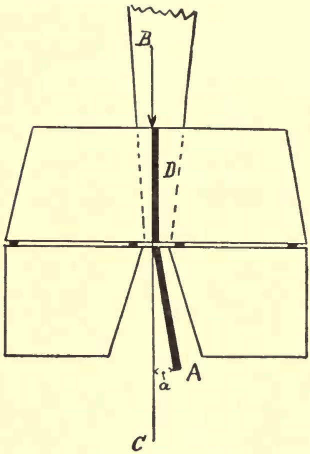


Fig. 58

To droop the elevators, a line *A B* (Fig. 59) is stretched over the top and on each side of the horizontal stabilizer *C*, in such a way as to follow its camber, and the droop measured from the upper side of the rear edge of each elevator *D* to the line.

As a general rule, whenever an aëroplane part is trued up, the turnbuckles are locked.

Controls.—The control cables must be so adjusted that by moving the controls sharply about 1/8 of an inch, the motion must be transmitted to the controlling planes without stiffness or slack. The control

Fig. 59

mechanism, pulleys and hinges, as all other moving parts of the machine, must be well lubricated with graphite to work freely and smoothly.

Rigging Care and Faults

The greatest care must be exercised in handling all parts of the machine in assembling and truing them up, to avoid damage, and in adjusting them properly.

In truing up an aëroplane, a great deal depends on the perfection of the tools used and the way they are handled.

The adjustable end wrenches, for instance, must have the right opening and the fixed end wrenches must be the proper size in operating the nuts, otherwise they will round their edges and spoil them. The levels and straight edges must be perfect, and to make sure of this, they must be tried before using them. To this end, the straight edge is clamped lightly in a vise and leveled, then the level is reversed on exactly the same place and the bubble watched carefully to see if it marks center again, in which case, it is moved slowly along the entire length of the straight edge to ascertain if it is perfectly straight throughout. The line used for the adjustment of the dihedral angle must be well stretched to prevent it from sagging and giving a wrong measurement.

The wires must be given the proper tension: if they are slack, the adjustments of the parts to which they are attached will be thrown out of true when under tension; and if they are too tight, they distort the parts and cause bending stresses, which are the most dangerous in an aëroplane framework. For the same reason, in handling a machine, care must be taken never to produce bending stresses, especially with struts. If an aëroplane is to be moved about, the points to be taken hold of are either the lower parts of the interplane struts or the upper parts of the undercarriage struts. Some machines have hand holes at the wing tips to facilitate their handling without damage. Special care must be had not to use the trailing edges of the wings as a holding point to move a machine, as they are weak and break easily.

The turnbuckles must be well lubricated, must work freely, but not loosely, and must be properly locked soon after the adjustments of the wires to prevent their slackening.

All nuts must be closely cotter pinned, that is, the pins must be very close to the nuts to avoid their loosening.

The controlling planes deserve special consideration in mounting and truing them, because they are essential to the safety of the aviator.

The engine rails must be leveled with the greatest of care, as they are the basis of all other adjustments and the slightest error in them throws the entire machine out of true, especially at the tail end, where the error will be greatly increased.

The balance of the machine depends on the way it is trued up. If, for instance, the angle of incidence is smaller or greater than it should be or the stagger improperly adjusted or the fuselage distorted downward or upward, the longitudinal stability will be affected and the machine will fly tail high or tail low. The lateral stability is affected by setting the wings at a different angle of incidence, thus causing one wing to fly low and consequently the other high, owing to their different lifting power. This same fault causes the machine to swing around, due to the difference in the drift of the wings, thus unbalancing the machine directionally. If the fuselage is distorted sideways, the machine has a tendency to circle around, as, in this case, it will be offering more keel surface on one side than on the other. If the controlling planes are not set at the proper angle or they are distorted, the control will be inefficient. If the angle of incidence of the wings is greater than it ought to be, besides unbalancing the machine longitudinally, causing it to fly nose high, it will produce poor flight speed, due to the increased resistance.

In conclusion, every error in truing is felt by the aëroplane, and too much emphasis can not be laid on the fact that the adjustments must be scrupulously exact.

CHAPTER IV

PROPELLERS

Theory.—Propeller and mystery are synonymous. In our Year of Grace 1919, nobody knows exactly what a propeller is. This being the condition of things at the present day, we can only accept with the benefit of doubt whatever information we can gather in regard to propellers.

The original theory considers the propeller a section of a screw and therefore the blades portions of the thread; which means that the propeller, in revolving, screws itself into the air and converts its rotary motion into a linear motion. The reason why only a portion of the thread is used is that a small slice of it is found sufficient for propeller purposes. The number of sections used represents the number of blades, which are made much longer than the thread, because in this way they are more efficient.

The theory most commonly accepted to-day is based on the analogy of the propeller blade with a plane, the difference being that the plane moves in a straight line, while the blade moves in a circle, advancing in the meantime in a straight line and consequently describing a spiral path; in other words, the propeller blade is considered a revolving inclined plane, although even those who accept this point of view admit that it is not absolutely exact, but very useful as a basis for calculation, whose results conform very closely with those obtained by experiment.

The new theory is, therefore, a modification of the old one, substituting a plane for a section of thread, but, admittedly, the facts deny the principle. The outcome is that both theories are found wanting and in practice it is necessary to use empirical formulas to solve propeller problems.

Another point of view taken by modern experimenters is the application of the reflection or batting theory, that is, the assumption that the blade in striking the air causes it to jump off at the same angle of entry and the reaction imparts a forward motion to the blade. Although this hypothesis is very plausible and seems to be in very close accord with facts, it is not sufficiently developed to be accepted just now and we are forced, therefore, to follow the mixed principle of the screw and plane.

The capital difference between a screw working its way into a nut and a propeller screwing itself into the air is due to the fact that the air is not solid like the nut and the propeller blades can not get as good a grip on the air as the screw on the nut, the result being that the air slips back and the propeller can not advance the full distance it ought to according to the angle of the blades. This brings us to the consideration of three different quantities: the distance the propeller ought to travel, the distance it actually travels and the distance lost. If we consider these quantities for one revolution only, we will have the following definitions: theoretical pitch is the distance through which the propeller would advance in one revolution if it moved in an unyielding medium; effective pitch is the distance actually traveled in one revolution; slip is the difference between the theoretical and the effective pitch.

The pitch depends on the angle of the blades or angle of pitch.

If the pitch of every point of the blade of a propeller is to remain constant, the angle of pitch must increase as the hub is approached, because the nearer we get to it, the smaller become the diameters of the circles described by the propeller when revolving and, consequently, the smaller the circumferences of the circles.

If we mark the points *A*, *B*, *C* (Fig. 60) on one blade of a propeller *D* and then we cause it to revolve on its axis just once without advancing, these points will describe circles,

which will be smaller the nearer the point considered is to the hub *E*. From this, it is clear that the greatest circle is described by the propeller tips and the smallest by the center of the hub, where a circle is represented by merely a point,

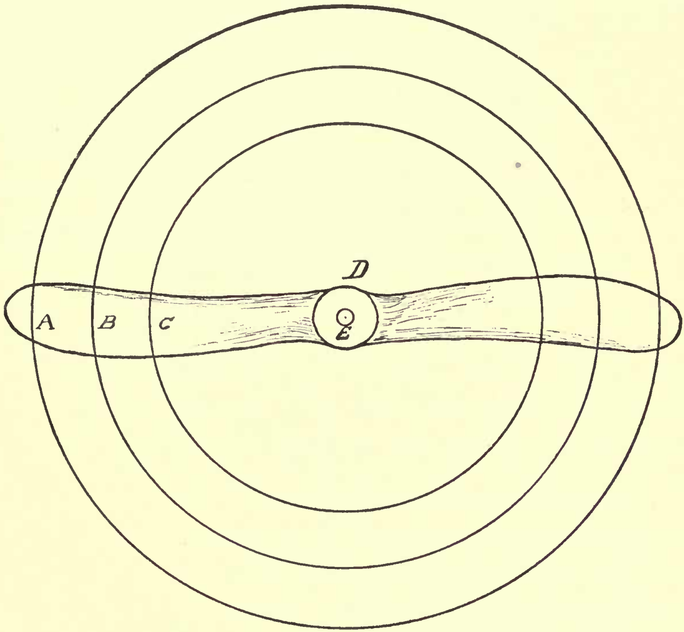


Fig. 60

consequently the smallest angle is at the tips and the biggest would be at the center of the propeller, provided that we could build a propeller without a hub, and even if we could, the angle would be of no use whatever, as it would be practically a right angle.

To make this clear, let us consider the circles described by the points *A*, *B*, *C*, as the bases of screws having all the same length (Fig. 61). If we want these screws to advance their full length in one revolution in their respective nuts, it is evident that each one must have just one thread, starting

at the top and ending at the bottom of the same side of the screw. If we wrap each screw with paper once around without overlapping the ends, mark on the paper the path of the thread and then unwrap and flatten it out, we find that the thread is the diagonal of the rectangle, which represents the development of the lateral surface of each screw (Fig. 62).

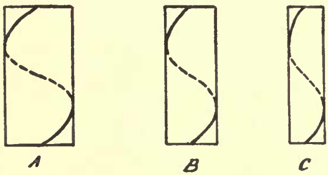


Fig. 61

If we now cut the rectangles along the diagonals, and take one-half of each one, we will have three right-angled triangles, whose respective height represents the distance advanced by

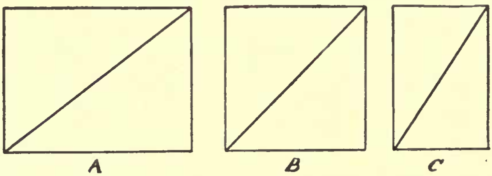


Fig. 62

each screw in one revolution or the pitch, which is equal in all three; the bases represent the developed circumferences of the circles of the bases of the screws and the hypotenuses represent the threads. The triangle thus formed is the triangle of pitch (Fig. 63).

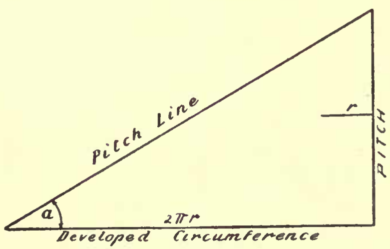


Fig. 63

If we put these triangles one on top of the other, having the biggest at the bottom and the smallest at the top, in such a way as to make the heights coincide (Fig. 64), we see that the angles A, B, C are not equal, but C is bigger than B and B bigger than A. As each angle represents the

angle of pitch of each screw, we see that the smaller the screw, the bigger is the angle of pitch and the steeper the pitch line which the thread must follow.

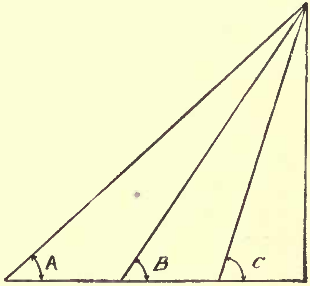


Fig. 64

A small section of each screw, cut across its longitudinal axis (Fig. 65), will act in the same way if screwed in its nut, because the slice of thread left will work its way through the nut just the same as if the thread were in its entirety.

We have come to this conclusion by starting from the assumption that the points *A*, *B*, *C* were taken on the same propeller and, consequently, what we have found in the case of the screws of different diameters and equal heights applies to these points, and if we curve around the triangles, so that the bases form circles, and we put them one inside the other (Fig. 66), the hypotenuses indicate the pitch lines

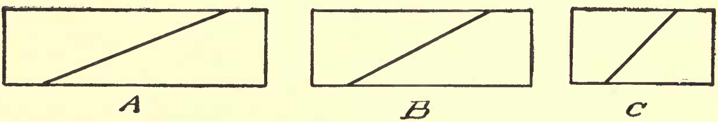


Fig. 65

of the points *A*, *B*, *C*, that is, the spiral paths which they would follow respectively if the propeller advanced through the air. In other words, we may consider a screw propeller as composed of an immense number of screws one inside the other, out of which all the unnecessary parts have been cut out, leaving only the center screw as a hub and attaching to its thread the threads of all the following screws. This would give us only one blade, which, of course, can be reproduced, giving us the means of making a propeller with as many blades as desired; but, following the analogy of

the propeller blade with the plane, the same law of interference which limits the gap holds true, but only in so far as it is applicable to the propeller.

In the case of superposed planes, we are free to make the gap the distance required or to stagger the planes, but with a propeller this is not possible, as the blades are fixed both in position and distance, and the only thing left is to make the width of the blade proportional to the gap or vertical distance between two consecutive helicoidal paths in order to regulate the amount of compression and rarefaction caused by the camber of the propeller and avoid interference. This means that the greater the number of blades of a screw propeller, the smaller must be the width of the blades and, consequently, the greater their aspect ratio.

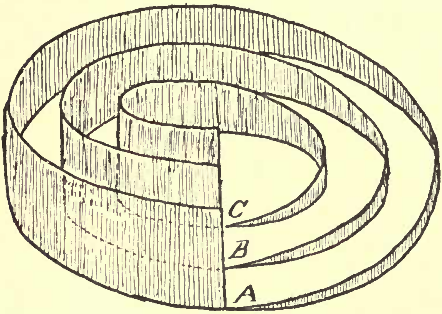


Fig. 66

The consideration of aspect ratio brings us to that of the diameter of the propeller, which is of the greatest importance, because a propeller of large diameter is more efficient in the utilization of power for several reasons. The thrust or power delivered by the propeller is concentrated on its blades and, therefore, the larger the area on which the thrust is distributed, the smaller its proportion for unit surface and the more able is the propeller to withstand the stress without breaking. To obtain the greatest efficiency, all parts of the blade should do the same amount of work, but as the angle of pitch increases towards the hub, the nearer we get to it, the smaller will be the thrust drift ratio, the greater the disturbance of the wash caused by the hub and the smaller the efficiency, so that the greatest quantity of work,

if not all of it, is done by about two-thirds of the outer part of the blade, the inner part being designed for low resistance rather than for driving. An increase in diameter really means an increase in the efficient part of the blade, as the further out we go, the smaller we find the angle of pitch and the greater the thrust drift ratio and, consequently, the greater the efficiency. The efficiency of a propeller increases with the increase in diameter, because the area swept by the propeller increases with the square of the diameter, which results in a reduction of slip: the greater the diameter, the lower the speed necessary to run the propeller and in consequence of both the increased surface and the diminished speed, the propeller gets a better hold on the air and does more useful work, reducing to a minimum the wasteful slip.

While we can safely say that a screw propeller must have a large diameter to be more efficient, we must consider, on the other hand, the limit imposed by the strength and weight of the material.

Another very important consideration is the proportion between the pitch and the diameter of a propeller or pitch ratio, which varies for different cases of service, a high-speed machine requiring a higher pitch ratio than a low-speed machine. To obtain the best efficiency, the pitch must be about 1¼ times the diameter, but when we take into consideration the diameter of the propeller, which must be as large as possible to be more efficient, the high speed of the gasoline motor and the relatively slow speed of the majority of the machines used to-day, we see that it is not always possible to obtain the pitch ratio of best efficiency, and we find that the propeller used at present for aëroplanes is of finer pitch than that of best efficiency.

In the case of a machine whose flight speed is 50 M. P. H., with a motor running at the speed of 1100 R. P. M. and an 8-foot diameter propeller, we find that the effective pitch must be 4 feet, which is just one-half the diameter of the

propeller, instead of 10 feet, as it ought to be for best efficiency. If the flight speed of the machine were instead 125 miles per hour, then the effective pitch would be 10 feet and the requirement of best pitch ratio fulfilled. From this, we see that as the speed of the machine increases, the incompatibility between the speed of the motor and the pitch ratio decreases, and in the future, when all machines will have reached the highest speed, this incompatibility will be entirely eliminated. At the present, this could be accomplished by gearing down from the engine to the propeller, but as this would cause a loss of about 4 per cent of the power and as the loss of efficiency with the direct coupled propeller is not great, the direct drive is preferred, especially as it produces a lower torque on the crank shaft and a consequent lower effect of the propeller torque on the machine.

A screw propeller is usually designed for the greatest velocity of an aëroplane, so that for a diminution in speed, the efficiency of the propeller diminishes also.

In laying out a constant pitch propeller blade, the first consideration is the determination of the blade angles at different radii as modified by the slip; then the centers of figure of the sections, which should all coincide with the axis of the blade; and, finally, the centers of pressure of the different sections, which should be so disposed as to avoid any twisting effect on the blade.

A matter of controversial nature is the existence of cavitation in an aëronautical propeller. Cavitation would be the rarefaction of air produced in the space immediately in the rear of a swiftly revolving propeller blade, due to the rapid cleavage of the air by the blade and the relatively slow action of the air in closing in behind the moving blade, and while it is generally said to make its appearance at about 1500 R. P. M., there are those who flatly reject the theory in the case of aëronautical propellers. Cavitation is admitted by all to exist in marine propellers, and this, coupled

with the fact that the aspect ratio of a marine propeller blade is limited by the much greater pressure reaction due to the much greater density of the water as compared to the air, explains the lower efficiency of a marine propeller, which at most is about 75 per cent, while for aëronautical propellers is about 85 per cent. No material known to-day would stand the increased pressure due to an attempt at increasing the efficiency of a marine propeller, while for air propellers the use of the softest wood would compare far better.

In regard to the position of the propeller in front or in the rear of an aëroplane, there are advantages and disadvantages in either case.

The power used to drive the machine forward is spent in imparting a forward motion to the air, so, if we place the propeller at the rear, it will be running in air which is already moving forward at a great rate of speed and this has the effect of greatly reducing the slip, and if the slip should be equal to the forward motion of the air, then the apparent slip, that is, the difference between the velocity of the propeller and the velocity of the machine, would be zero and the machine would be flying just as fast as if the propeller were screwing its way through a solid medium. It may happen, and it has already actually happened with steamers, that the forward motion of the fluid in which the machine is running is greater than the slip, and in this abnormal case, the machine would be going faster than if the propeller were running in a solid nut. This is the case of negative slip, that is, the velocity of the machine is greater than the velocity of the propeller. But while these are merely theoretical considerations, some of which may or may not materialize, the fact remains, as we have already seen, that a propeller in the rear means a specially constructed and clumsy fuselage, with attendant outriggers, struts and wires, which increase the weight and the drift of the machine, probably eliminating altogether

the advantages of having the propeller in the rear. When the propeller is in front, the fuselage can be built in the best stream-lined shape, which reduces the resistance and weight to a minimum, and besides, due to the fact that the air is blown against the wings, the lift is more than doubled, both because the speed of the machine relatively to the air is increased and because more air is engaged, and we know that the lift is proportional to the amount of air engaged and to the square of the velocity. While this is a great advantage, it is in the meantime a great disadvantage, because the air blown against the machine has also the effect of pushing it backward, so that the effective forward motion is the difference between the two forces; and although the increased lift enables us to reduce the span, on the other hand, the increase in passive drift requires the employment of a considerably greater horse power.

Problems.—To find the angle of pitch at a given point of a constant pitch propeller, it is necessary to know the pitch, and vice versa; that is, to find the pitch, we must know the angle.

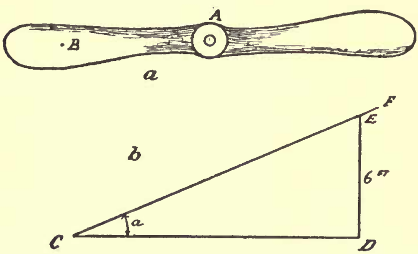


Fig. 67

If the pitch of a propeller A (Fig. 67a) is 6 feet and we want to find the angle of pitch at a given point B, 3 feet out from the center, we can solve the problem graphically by means of the triangle of pitch.

First we find the circumference described by the given point B in one revolution by multiplying the radius by 2 to find the diameter and then by 3.14; that is, $3 \times 2 \times 3.14 = 18.84$. We mark this distance on a line $C\ D$ (Fig. 67b); from one of its ends D draw the perpendicular $D\ E$, equal to the pitch, and from the other end C, a line $C\ E$ which joins the extreme points of the developed circumference and the

pitch. The angle a, formed by the base and the hypotenuse of the triangle, is the angle of pitch at the given point B of the propeller.

If, instead, the angle a is known, we find the circumference $C D$, lay the angle on one of its ends C, from this point draw an indefinite line $C F$, inclined at an angle equal to that given a, and from the other end D the perpendicular $D E$. The point of intersection E of the two lines determines the pitch $D E$.

If we want to find the pitch of a propeller in a numerical way, given the machine speed, the motor speed and the propeller slip, the problem is solved in the following way:

If the data are these: machine speed, 50 M. P. H.; motor speed, 1100 R. P. M.; and the propeller slip, 20 per cent; we reduce first the miles per hour to feet per hour by multiplying 50 by 5280, then we divide this product by 60 to find the feet per minute, and finally we divide this quotient by 1100 to find the number of feet in one revolution. This last result tells us what the effective pitch of the propeller should be to get the speed of 50 M. P. H., and as the slip is 20 per cent, we must increase accordingly the number found to obtain the theoretical pitch of the propeller, so that when the slip is deducted, we actually get the necessary effective pitch.

We have then:

$$50 \times 5280 = 264000, \frac{264000}{60} = 4400, \frac{4400}{1100} = 4.$$

If the slip is 20 per cent, the efficiency of the propeller is 80 per cent, and as 4 represents this 80 per cent, we can get the theoretical pitch from the following proportion:

$$4 : 80 = x : 100, \frac{4 \times 100}{80} = \frac{400}{80} = 5.$$

The pitch of the propeller is, therefore, 5 feet.

Manufacture.—Propellers may be made of metal or wood.

Metal propellers have the advantage of cheapness as compared with wooden propellers, but they have, on the other hand, certain drawbacks, which give rise to objection to their use. First of all they are heavy, and if they should burst under the strain of high velocity, the fragments are apt to cause damage. Then they bend easily, and on account of their great elasticity they vibrate when in use. Another drawback is the quasi impossibility of obtaining an even surface blade, and finally the difficulty of attaching the blades to the propeller arm.

If a metal propeller is to be used, perhaps aluminum is the more suitable to make the surfaces of the blades, because its lightness permits of relatively thick blades, which, increasing the moment of inertia, preserve their shape. But, all things considered, wood propellers are the best, even if they cost more.

Wood propellers are light, and this is their chief characteristic, from which many a good advantage is derived. Being light, they can be made very thick. Their thickness makes it possible to shape the blades in a way to offer the least resistance to motion, and again to cause an increase in the moment of inertia, with a consequent increase in the resistance to flexure, which permits, therefore, of a very high rate of speed with very little probability of bursting, as wood possesses greater tensile strength than the best metal, especially with the grain running in the sense of the length of the blade; but even if the propeller should burst, the fragments being light would not be so dangerous.

Wood propellers can be made in one single piece or in laminations, which are glued together with insoluble glue. One-piece propellers are cheaper, but as it is hard to find wood of straight grain without any flaws, the laminated propellers are to be preferred, because they allow the use of the best kind of wood.

A propeller is usually made with five or six laminations of mahogany, walnut or oak. The laminations, besides being

glued together, are held in place by dowels driven through them at equal distances. They are held in a press until thoroughly dry, then they are cut by machinery into propeller shape and finished by hand.

The wood used for a propeller must not be very dry, but it must contain a given amount of moisture, which must be kept constant, and to this effect the propeller is painted with a special filler and then varnished several times.

Some propellers have metallic protections at the tips and

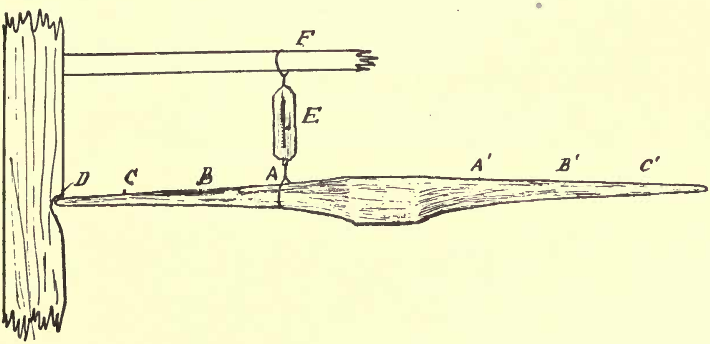


Fig. 68

as the metal can not adhere to the wood, if the machine were in flight on a rainy day, the rain would filter through and collect at the tip, causing the metal to bulge up and tear the propeller to pieces owing to the terrific centrifugal force. To avoid this, small holes are bored at the tips of the metallic protections to allow the water to run out.

Balance.—A propeller must be perfectly balanced. There are different methods to try a propeller for balance, but the best is to mark equal distances from the center to the tip on both blades and to weigh the propeller at all the marks; for an equal distance from the center, the weight on one blade must be equal to that on the other. This is accomplished by inserting one of the tips *D* (Fig. 68) in a notch cut in a wall and hooking the propeller to a spring scale *E*

suspended from a bar F and weighing it at the different equidistant marks A, B, C and A', B', C'. The weight at the point of the first mark A on one side of the propeller must be equal to that of the first mark A' on the other side; the second equal to the second, and so on.

A slight error in the balance can be corrected by additional coatings of varnish on the blade which weighs less or by scraping off some of the material near the hub of the blade which is heavier. If the difference is too much and can not be corrected in this way, the propeller must be rejected.

Test.—To see if the pitch angle of a propeller is correct, it is measured on both blades at equal distances from the center by means of a protractor or the triangle of pitch. The angles equidistant from the center must be equal. To accept a propeller as good, the pitch angle must be within ½ a degree of the proper angle.

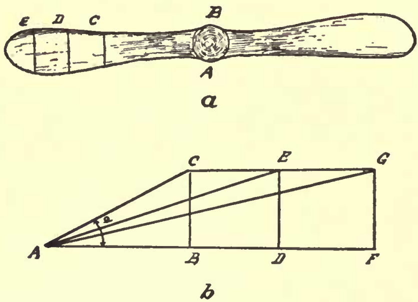


Fig. 69

To test a propeller for warpage, the following method may be used:

Starting from the center A (Fig. 69a) of a propeller B, we mark different points C, D and E on one blade; then, by means of a protractor, we measure the angle a at the inner point C and lay it off at one end A (Fig. 69b) of the line $A\ B$, which represents the developed circumference of the circle described by the given point; from the same end A, we draw an indefinite line $A\ C$, inclined at an angle a equal to that measured, and from the other end B, the perpendicular $B\ C$, which is the pitch of the propeller. The same process is repeated for all the other points and if the propeller is not warped, the lines which represent the pitch should all be

equal, $B\ C=D\ E=F\ G$. To facilitate the work, we draw the parallel $C\ G$ from the point of intersection C of the first pitch found to the line $A\ B$, which represents the developed circumference of the first point, and if the blade is correct, all the other points fall exactly on this parallel line; but if they fall within or without it, the angles are smaller or larger than they ought to be and the blade is warped. If, instead, it is not warped, the same system is followed to test the other blade.

The length of one blade must be equal to that of the other or the difference must fall within 1/16 of an inch to accept the propeller as good.

The width and the camber of the blades must be equal at points equally distant from the center.

An error of 1/8 of an inch is allowed for the straightness of a propeller.

The joints of the laminations must be all perfectly closed and the surface very smooth throughout.

The hub hole and the bolt holes must be perfectly straight and at right angles with the face of the hub.

Care.—A propeller must be kept always in a vertical position to protect it from distortion, and the best way is to mount it on a wooden peg, which fits the hub hole exactly.

To prevent the blades from warping, the place where the propeller is stored must be neither very damp or very dry, nor such as to allow the sun rays to fall on it. If these rules are disregarded, the propeller will lose its efficiency and give rise to flutter, which will stress the bearings and crank shaft of the motor and probably tear it to pieces.

Boss.—Boss is a metallic device used for the attachment of the propeller to the shaft of the motor.

The simplest form of boss consists of two flanges, one of which, A (Fig. 70), is permanently attached to the shaft and has eight threaded holes, while the other B is a separate piece with plain holes. The propeller C is mounted on the shaft between the flanges, which are held together by eight

bolts on whose points are also screwed and cotter pinned the nuts. While this is the simplest form of boss, it is not the best, because the bolts are shaken and loosened by the revolution of the propeller, which is liable to break.

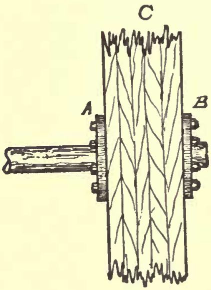


Fig. 70

A good form of propeller boss is that used for the Gnome motor (Fig. 71). In this case, the flanges are also two *A* and *B*, but they are both attached to the propeller by eight bolts, and one of the flanges *A* has a tubular projection *C* with a keyway *D*, cut in the inside, in which, when the propeller is mounted, fits a key *E* laid in a slot *F* cut in the shaft, and the propeller is then held in place by a nut *G* screwed on the crank shaft. To prevent this nut from unscrewing, a ring spring *H* is mounted on it in such a way that one of its points *I* goes through one of three holes *J* bored in the nut and inside one of four slots *K* cut on the end of the crank shaft.

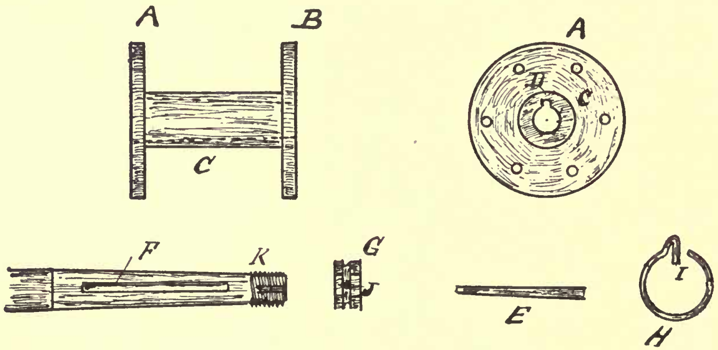


Fig. 71

The Curtiss boss (Fig. 72) is similar to the Gnome, with the difference that, beside the eight bolts, there is a nut *A* screwed on the threaded end of the tubular projection to help fasten the flanges on the propeller, which is then held

in place on the shaft by screwing on it another nut *B*. Both nuts have three holes for the use of springs, which lock them in the slots cut in the tubular projection and in the shaft, as in the Gnome boss.

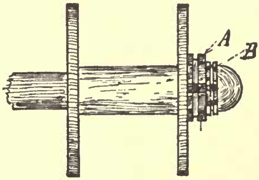


Fig. 72

A propeller must be mounted at right angles with the shaft. To test the alignment, a stick is brought in contact with the tip of one blade and held in position while the other blade is brought around to see if it touches the point of the stick as the first blade. If this is not the case, the nuts must be tightened on the side of the blade which forms the greater angle with the shaft, until the propeller is perfectly aligned.

As in an aëroplane the motor is cranked by means of the propeller, another point to consider in mounting it is to put it in such a position that it can be grasped easily and the motor started quickly. This means that the propeller must be in an inclined position and one of the cylinders of the motor on compression, near the firing point. If this is not done, it will be very dangerous and hard, if not impossible, to start the motor.

CHAPTER V

MAINTENANCE

Inspection.—With the exception of the medical profession, there is perhaps no other calling in life which has more responsibility than that of the aëroplane mechanic: to him is entrusted the fate of human beings, who may be dashed to instant death through a mere carelessness on his part, and there can be no greater remorse than that caused by the remembrance of having destroyed human life through lack of care.

To avoid these dire consequences, it is imperative that an aëroplane be scrupulously inspected before and after every flight, daily and weekly, and maintained in the best condition.

To inspect a machine before or after a flight, the most important parts are looked after, such as the bracing and control wires, to see if they are properly tensioned and in good condition. The machine must also be cleaned from the dust that collects on the wires, which are oiled or greased, on the planes and on all the other parts in general. When the machine starts from or lands on wet ground, the wheels throw off mud on the under side of the wings and it must be removed, which is easy to do if the mud is wet, but if dry, it must first be dampened, otherwise the fabric may be damaged in scraping it off. The motor also throws oil all over the machine. If any of it goes on the planes, it must be cleaned with gasoline, acetone or hot water and soap. When soap is used, it must be of the kind that has no alkali, that is, no soda or potash, which damages the fabric.

In a daily inspection, besides what is done for a flight inspection, all the adjustments of the machine must be looked after, to see if the straightness of the wings, the dihedral

angle, the angle of incidence, the stagger and the controls are in perfect order.

In a weekly inspection, all the parts of the machine, from the biggest to the smallest, must be carefully examined, and the best way to do this is to have an inspection card with all their names written down, to check them off, one after the other, as they are examined.

The wires are first inspected to see that they are not damaged, scored, kinked or rusty, and then they are greased or oiled.

The control cables must be inspected thoroughly, especially around the pulleys, where the wires are apt to fray. If even one only of the small wires is broken, the cable must be replaced. As these wires are covered with grease, they must be washed with gasoline to facilitate the inspection. The control cable connections must also be examined to see if they are in perfect order.

The fittings must be looked after for signs of cracking at the corners.

All the locking arrangements, that is, the safety wires of the turnbuckles, the cotter pins and the nuts, must all be properly set in place.

The axle and spokes of the wheels, the rudder post, the tail skid post and the struts must be examined for distorsion and replaced if necessary.

All moving parts, that is, wheels, pulleys, hinges and control mechanism must be well lubricated with graphite.

The shock absorbers of the wheels and tail skid must be thoroughly inspected, to see if they have the proper tension and if they show any signs of wear.

The fabric must be examined for wear and tear, and for the condition of the dope and varnish.

It is a good practice to stand some distance away from the machine every time it is adjusted, to get used to the way it looks and learn to see at a glance its condition, thus saving time in the inspection. If, for instance, we stand in

front of the machine and look at the front struts, when they are properly aligned, they must cover the rear ones, and if we look at them from the side, the outer struts must be in a line with the inner struts. The straightness of the wings, both in regard to the leading and trailing edges, can be easily detected by looking at them from the front or rear of the machine.

It is well to time every inspection, either partial or general, to know exactly how long it takes and be ready for any emergency.

Forced Landing.—In case of a forced landing in a cross country flight, the first thing to do is to choose the proper ground to start from at any time, because the weather may change suddenly and if the proper spot is not chosen beforehand, the start can not be made immediately; then the machine must be turned around to face the wind and, if possible, put under shelter. It is a good plan to dig trenches and sink the wheels in them or, if this is not possible, to block the wheels to prevent the wind from blowing the machine away.

If the machine is to remain exposed any length of time on a windy day, it is well to picket it by tying ropes from the lower part of the interplane struts or the upper part of the undercarriage struts to pickets driven in the ground. In this case, all points where the cord comes in contact with the fabric must be padded with soft material, otherwise the rubbing of the cord spoils it.

The controls must be lashed fast to avoid damage to them by being blown about by the wind.

If the machine is to stay in the open overnight, the propeller must be covered to protect it from moisture.

Repairs.—Wood.—The repairs of the wooden parts of an aëroplane usually consist in replacing broken members with new ones, unless it is an emergency repair in an exceptional case, when the highest skill and attention are necessary to prevent the collapsing of the part temporarily fixed.

In substituting a new piece, care should be taken to see that it fit exactly, and if there are any holes for the passage of bolts, that they be the proper size. If the holes are larger than they ought to be, the bolts move and throw the parts fixed out of adjustment, and if they are smaller, the introduction of the bolts may split the wood.

The washers used for wood must be larger than those for metal to give them a greater supporting surface and prevent their sinking into the wood.

Metal.—The fittings are generally made with several strips of pressed steel, cut in the proper shape, riveted together, brazed and coated with non-rusting paint. If this process is not available in making a fitting, the best thing is to make it in one piece, cutting the plate accordingly. In bending the plate, care must be taken not to form sharp corners, as they weaken the metal and cause it to break, and as pressed steel has a grain running in one direction only, the bends must be made across the grain, otherwise they are weak.

In substituting an old wire with a new one, it is essential to use the proper quality, and to test it, the easiest way is to lock in a vise a short piece of it and bend it at a right angle. If the wire flattens at the curve, it is too soft; if it roughens, that is, shows small cracks at the outside of the bend, it is too hard; and if it does not show any of these two signs, it is the right kind to use.

The solid wires inside of planes must be coated with white non-rusting paint, and not with red paint, because any signs of rust do not show when covered with red, while they do through white, and give a warning. This white paint is also more elastic than the red and does not crack with changes in temperature. The wires must be dry before being painted, otherwise the paint does not adhere, peels off in due time and exposes the wires, thus failing to protect them from dampness.

As all wires must be looped to be used, it is necessary to know how these loops are made.

To make the ferrule and loop, the solid wire is inserted in a ferrule A (Fig. 73a) and in a shank B, the wire is looped, the shank slid in the loop, the ferrule slipped back to rest against the loop, the short length of the wire bent over the ferrule and then cut off, leaving just a small hook to hold the ferrule in place (Fig. 73b).

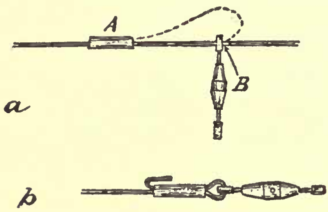


Fig. 73

In this process, the following points must be observed: in making the loop, a good length of wire must be allowed to be easily bent before cutting, as solid wire is stiff and can not be bent if it is short; and the loop must be oval, well defined, symmetrical, without scores or angular corners to weaken the wire and cause it to break, and of small size, otherwise it elongates easily under tension and throws out of adjustment the parts to which it is connected.

If no ferrule is available, one may be made by cutting a short copper tube of suitable size and flattening it out just enough to make it oval.

The ferrule and loop is often dipped in solder to fill in the space between the ferrule and the wire.

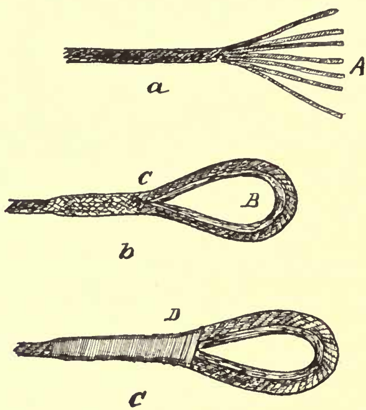


Fig. 74

A spliced loop is made by unwinding the strands of a wire A (Fig. 74a), making the loop around a thimble B (Fig. 74b) and inserting one strand at a time in its closed strands C by prying them open with a pointed tool. After

some length has thus been spliced, one wire of each strand is cut off and the splicing continued; when another length is spliced, another wire is cut off, and so on, until the loop is finished. The wires are cut off gradually to taper the splicing down towards the end. The splice is served with a fine string or a wire *D* (Fig. 74*c*) to protect it.

The thimble and loop is formed by inserting a thimble in the loop, winding its ends *A* (Fig. 75) with fine copper wire, skipping a couple of spaces *B* and *C* about $^1/_8$ of an inch, cutting the end *D* of the wire at a slant to taper it down and thoroughly soldering loop and thimble.

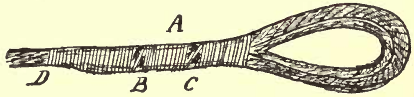


Fig. 75

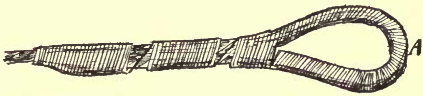


Fig. 76

The wrapped and soldered loop requires a close winding of copper wire around the part to be curved, to prevent the opening of the coils at the outside of the bend *A* (Fig. 76). The remainder of the work is done as in the thimble and loop.

All these loops are fitted with shanks before being closed.

As the two last loops are soldered, it is necessary to know the soldering process to be able to properly finish the work.

Soldering.—For common soft soldering, it is necessary to have: solder, flux, blow torch or blow furnace and soldering iron.

The solder is an alloy of tin and lead, usually in equal parts, and, therefore, known under the name of "Half and half." Sometimes, more tin is used and the solder is then harder.

Flux is a substance that promotes the fusion of metals, prevents their oxidation under the action of heat and cleans their surface. It may be solid, in paste form or liquid. That

used for soft soldering is generally chloride of zinc, which is formed by dissolving zinc in hydrochloric acid.

Hydrochloric, or muriatic acid, as it is commonly called, is a colorless, corrosive gas, having a sharp penetrating taste and suffocating smell. It is exceedingly soluble in water and when it comes in contact with the air, it condenses the moisture, forming dense, white clouds.

What is commercially known as hydrochloric acid is a strong aqueous solution, colored yellow by impurities, such as iron or organic substances. Pure hydrochloric acid is a solution of pure gas in distilled water and is colorless. A concentrated solution of hydrochloric acid gives off fumes when exposed to the air, and when heated, the gas evaporates.

The commercial acid is obtained in the soda factories by pouring strong sulphuric acid on common salt, which gives the following reaction:

$2\ Na\ Cl$	$+$	$H_2\ S\ O_4$	$=$	$Na_2\ S\ O_4$	$+$	$2\ H\ Cl$
Sodium chloride		Sulphuric acid		Sodium sulphate		Hydrochloric acid

The hydrochloric acid thus given off passes through special towers, over whose walls flows a constant current of water, which dissolves the gas and collects it at the bottom of the towers.

To prepare the flux, zinc is treated with hydrochloric acid, which gives the following reaction:

Zn	$+$	$2\ H\ Cl$	$=$	$Zn\ Cl_2$	$+$	H_2
Zinc		Hydrochloric acid		Zinc chloride		Hydrogen

This is known to the trade as "cutting the acid," which is considered "raw" before being cut; but, as we see from the chemical combination, what really takes place is the formation of chloride of zinc, which, if used as flux, prevents the oxidation of metals under the action of heat. To add to this property of the flux that of cleaning, a few drops of

raw acid are poured in it. As the solution must be saturated, a greater quantity of zinc is used than that necessary, to make sure that there is no more needed, and the surplus is removed after the combination ceases, which is indicated by the stopping of the bubbling caused by the reaction. The acid to be cut must be poured in an enameled earthen cup, as there is development of heat during the combination and if a glass vessel were used, it would crack.

A blow torch is a lamp that burns gasoline mixed with air to give a hot, blue flame. Its parts are: a tank *A* (Fig. 77) which contains the gasoline, a hand pump *B* to force and compress the air in the tank, a needle *C*, a needle valve *D*, a holed burner *E* which mixes the gasoline vapor with the air and gives a blue flame, a drip cup *F* in which gasoline is burned to heat the burner, a filler plug *G* to close the tank, and a tube *H* through which the gasoline is forced up to the needle valve by the air pressure.

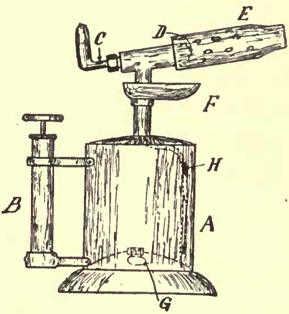


Fig. 77

To make the torch ready for use, it is turned upside down, the filler plug at the bottom unscrewed and the tank filled about ¾ full with clean gasoline. To prevent a leak, it is better to first soap the threads of the filler plug and then screw it tightly, using a wrench or an iron bar inserted in its hole to make sure that the joint is air-tight, but care should be exercised not to screw the plug unnecessarily hard, otherwise the bottom of the tank will be distorted and damaged, being very thin.

The torch is turned right side up and a good, heavy pressure of air supplied in the tank by means of the pump. A pressure of about 15 pounds is enough for a strong, blue flame, but the higher the pressure, the better the flame. If the plunger of the pump is of the kind that can be screwed

down, it must be screwed, as it has a needle point on its inner end to make a positive shut off.

The tank is now to be tried for leaks, as a leaky tank not only gives a poor flame, but it may also cause a fire on account of the gasoline oozing out through the leak and igniting. For this purpose, the torch is turned upside down; this brings the gasoline to the top part of the tank and in case there is a leak, it is easily found and stopped.

If there is no leak in the tank or fitting, the torch is turned right side up and the drip cup filled with gasoline by putting one hand against the mouth of the burner and opening the needle valve with the other; the gasoline strikes the hand, falls in the burner and from there drops in the drip cup. When this is full, the needle valve is closed, the gasoline lighted and the torch protected from currents of air, so that the burner may be thoroughly heated by the flame. Usually the amount of gasoline in the drip cup is enough to heat the burner properly, but sometimes, especially in cold weather, it is not sufficient, and in this case, it is necessary to heat the burner by means of a flame (either from another torch or a gas flame), as it is impossible to put more gasoline in the cup, which, being warm, causes it to vaporize.

If the tank has been previously tried for leaks and none found, then, to fill the drip cup, only a few strokes of the pump will suffice to supply enough pressure to force the gasoline out slowly, when the needle valve is opened, and fill the drip cup without the need of closing the mouth of the burner by the hand. Then the full amount of air pressure will be supplied to the tank. The drip cup may, of course, be filled from a separate source than the tank.

When the gasoline is nearly burned out of the cup, the needle valve is slightly opened and the jet of gasoline ignites. If it does not light from the flame of the cup, it must be lighted from the end of the burner and the flame allowed to burn in the burner tube as well as in the drip cup. When the gasoline is all burned out of the drip cup, the valve is opened

a little more and the flame allowed to burn low until the burner becomes thoroughly heated, then the valve is opened enough to give the desired flame.

A flame about 4 inches long for a quart and 3 inches for a pint torch generally gives the best results.

When through using the torch, the valve must be closed only sufficiently to extinguish the flame without using force, which enlarges the needle valve and ruins the burner. After the flame is out, the valve must be opened again for about one-quarter of a turn of the needle. This is done to prevent damaging the needle opening, because the heat causes it to expand, and when it cools down and contracts, if there is not enough room allowed for the contraction, it presses so tightly against the needle that it is hard to open and the consequent friction spoils the opening, rendering the torch useless.

The principle on which the torch works is this.

The pressure of air in the tank forces the gasoline out through the tube *H* and the valve *D*, and, as the jet rushes in the hot burner *E*, it is vaporized and mixed with the air sucked in through the holes of the burner by the current formed by the jet of gasoline. The mixture of air and gasoline gives a hot, blue flame.

From this, it is clear why the tank must not be filled entirely with gasoline, being necessary to leave room for the air, so that a high pressure can be brought to bear against the surface of the gasoline, because the greater the pressure, the more powerful the jet through the burner, the greater the suction produced, the better the mixture of air and gasoline, and the better the flame. To make sure that some air will be in the tank even when it is filled full, its bottom is made funnel-shaped, so that, besides facilitating the filling, it renders impossible the expulsion of all the air from it, although the amount left in is much less than that needed.

If the torch does not work, the tank must be examined

to see that the filler plug is screwed in tight, that there is the proper pressure, the right quantity of gasoline and no leaks.

If the burner smokes or does not give a blast when the tank is tight and the air pressure good, it indicates that the burner is dirty or clogged, in which case, it must be taken out and cleaned from the carbon formed around it as well as in the air holes of the burner. In reassembling, the joints must be soaped to prevent leaks.

If the washer of the filler plug is old or worn out, it must be replaced with a new one made of leather or, if leather is not available, with a soaped cotton string wound around the plug to the right, so that when the plug is screwed in place, it will tighten the string.

The air pump must be oiled often to keep the cup leathers soft, as the pump heats in use and the leather dries, causing the pump to work badly. A few drops of oil at a time and often will keep the pump in good condition and increase its life.

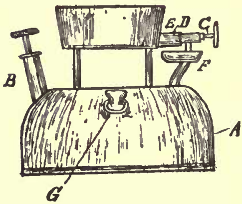


Fig. 78

When the torch is not in use, it must not be stored in a damp place or allowed to remain in contact with acid fumes, as it will oxidize.

The gasoline used for torches should be clean and kept in clean cans to avoid stopping the burner, and it should be of good quality to give the best results.

A furnace (Fig. 78) works on the same principle as a torch, but it differs in size, shape and material; being larger, flatter and made of iron with a few parts of brass, while the torch is mostly brass.

Although the make of a furnace varies and special instructions are furnished by the manufacturers, generally speaking, the following rules apply to the majority of them:

If the burner is rigid, it will, of course, be always in the right position, but if it is mounted on a swivel, it must be placed in a horizontal position to fill the drip cup, and the

needle opened only enough for the gasoline to fall in the cup.

The swivel action may cause a leak at the shoulder of the needle, in which case the stuffing box must be tightened.

To remove the burner, it is necessary to remove first the top chamber by turning the burner so that it stands upright, unscrewing the thumbscrew in the center of the chamber and lifting it off; then the burner and swivel are unscrewed from the standpipe, without taking apart the swivel at the union, as not only it is unnecessary, but it may cause a leak, if it is not properly reassembled.

To clean the burner, it must be taken off together with the swivel, the spiral core removed and cleaned thoroughly, forcing out all dirt from the hole in the center of the core by means of a fine wire, and washing the burner in gasoline. If the wire strainer cloth at the small end of the swivel is dirty, it must be removed and replaced with a new one, made of the proper kind of strainer cloth, rolled up tightly and forced into the hole, to keep out lint and dirt and save cleaning the burner oftener, and also to facilitate the vaporization of the gasoline.

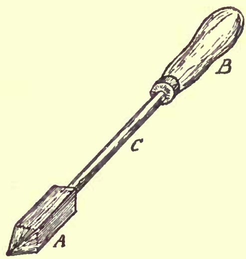


Fig. 79

In putting the burner back, care must be taken to set it in the proper position, so that the gasoline can fill the drip cup.

If there is a leak around the pump collar, caused by the washer being old, it must be renewed.

The so-called soldering iron consists in reality of a quadrangular prism of copper terminating in a pyramid *A* (Fig. 79), a wooden handle *B* and an iron bar *C* uniting both.

To prepare the iron for use, it is heated to a temperature just short of redness, its sloping end quickly filed bright, dipped momentarily into the flux and tinned by rubbing it on solder laid on a piece of tin or a hard wooden block.

The iron may be filed cold or warm, but it is better to file it warm, because, in this state, a mere shaking of the iron causes the old solder to drop off, and a few quick strokes of the file are enough to make the point bright without loss of heat. If, instead, it is filed when cold, it takes longer, the work is harder, the solder sticks to the file and spoils it, and after the iron is heated, it is necessary to file it again to remove the oxidation caused by the heat. In reheating the iron, after it has lost its proper temperature during the soldering process, care should be taken not to heat it quite to redness or the solder may burn off, necessitating a repetition of the tinning, nor to overheat it to such a temperature that the iron burns, and must be filed again, which means hard work, loss of metal and time.

The capital requirement for true soldering is that between the metal to be soldered and the solder used there should be a certain degree of alloying, an intimate union of the two thus taking place. Beside this, it is necessary that the metal be bright, clean and free from greasy matter, and that it be coated with flux to prevent its oxidation under the action of heat.

When chloride of zinc is used as flux, the metal soldered must be thoroughly washed to remove any trace of acid, which in due time would corrode it. For this reason, the loops that require soldering are dangerous, because the acid can not be all removed; but as long as they are still in use, it is well to know how to solder them.

A loop is first coated with flux and soldered on both sides with more solder than necessary; then it is laid on a hot soldering iron and pulled slowly along it, so that the heat melts the solder and causes it to filter through; and finally it is thoroughly washed with plain or soaped water. If the work is properly done, when the loop is cut, the wire looks as if it were solid instead of stranded.

The openings left in the copper wire winding are for the purpose of inspection, that is, to see if the solder filtered through.

From this process, it is clear that the flux remains inside the wire, the surrounding solder making it impossible to wash it out, and, consequently, it will exercise its corrosive action without being detected until the wire breaks.

Fabric.—The repairs in the fabric consist in sewing plain tears or patching holes. In either case, it is first necessary to remove the old dope by rubbing it off with a cloth moistened with acetone or by applying on it fresh dope and allow-

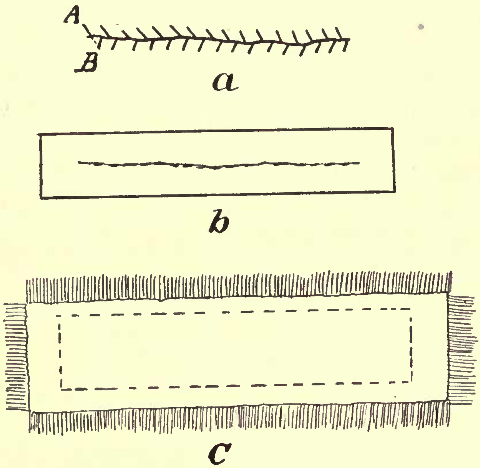


Fig. 80

ing it to cut the old one, when it is removed by means of a piece of cloth.

A plain tear is sewed with a baseball stitch (Fig. 80*a*), that is, a needle filled with single thread is passed through the tear, stuck from underneath in one side *A* of the torn fabric and pulled out, so that the knot remains unseen under the fabric, then the needle is inserted again in the cut, stuck in the other side *B* of the cut and pulled out, and so on. When the sewing is finished, the thread is cut off and the end tucked under the tear, which is doped, covered with a patch large enough to hide it (Fig. 80*b*) and the patch doped

also. After this is dry, another patch with frayed edges (Fig. 80*c*) is applied on it and coated with the regular number of coats of dope and spar varnish. The last patch is frayed, because the frays adhere better than the plain edges.

To repair a hole (Fig. 81*a*), it must be filled in with a piece of fabric, and to facilitate the work, the hole is cut into a regular shape with square corners, which are then slit (Fig. 81*b*) and the fabric tucked underneath (Fig. 81*c*) to double

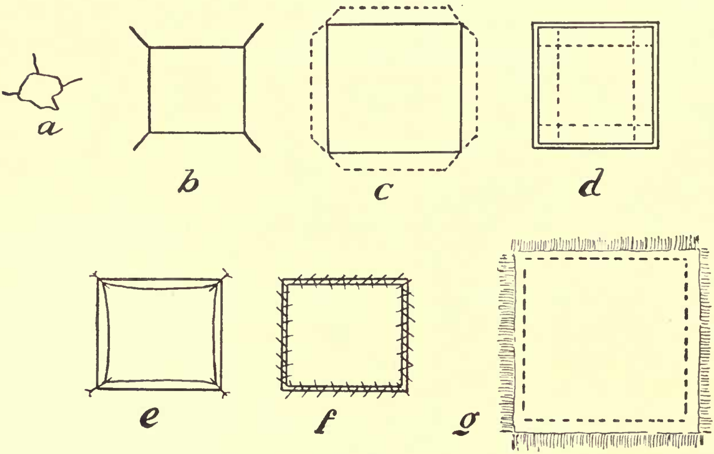


Fig. 81

it up and make it stronger at the edges, which are to be sewed. A piece of fabric is cut of such a size that when its edges are tucked under on all sides, it is about 1/16 of an inch smaller than the hole all around (Fig. 81*d*) to make possible the stretching of the fabric in sewing it. The corners of the fabric are now fixed in place by stitches (Fig. 81*e*) to ascertain that the patch is the proper size and to render easier its sewing, which is done with a baseball stitch as for a plain tear (Fig. 81*f*) and the work finished in the same way, that is, by doping on it a plain and a frayed patch (Fig. 81*g*) and giving the latter the required number of coats of dope and spar varnish.

Rubber.—A puncture in the inner tube of a tire may be repaired in an emergency case by means of a prepared patch, which is a disk of rubber covered with rubber cement protected by a cloth. To make the patch ready for use, the cloth is removed, gasoline poured on the cement and the patch left in this way for about 15 or 20 minutes. The tube around the puncture is washed with gasoline, sandpapered, coated with rubber cement and covered with the patch, which is held firmly against it by means of a weight until it is dry.

If the puncture is so small that it can not easily be seen, the tube is inflated and dipped in water: the bubbles formed by the escaping air indicate its location. The tube must, of course, be dry before applying the patch, which must be handled by the edges to avoid touching the cement with fingers soiled with oil or grease and spoiling its adhesive property.

If a steel brush, instead of sandpaper, is used to rub the tube, care must be taken to see that the wires are all even, as sometimes one of them protrudes more than the others and cuts the rubber all over.

A punctured outer casing or shoe is properly repaired by the vulcanizing process, which requires the skillful use of special apparatus, but the puncture can be temporarily stopped by means of one of the clamps made for this purpose and inserted in the casing against the puncture, to prevent the inner tube from blowing out through it. As a substitute for a clamp, a piece of thick rubber, leather, linoleum or anything stiff enough to stop the puncture temporarily may be used.

CHAPTER VI

FLIGHT HINTS

Methods of Instruction.—This chapter is not meant to teach anybody how to fly—flying "by correspondence" is not a possibility—but it simply aims at giving a brief explanation of how the theory of flight is applied in practice.

Flying can be learned in three different ways, but in each of them a previous thorough knowledge of the elementary theory of flight, aëroplane construction and gas engines is essential. With this premise, let us examine these three different methods.

A man that owns an aëroplane and has at his disposal a good stretch of level, clear ground, suitable for the initial runs up and down, may learn slowly and gradually the use of the controls before he attempts to leave the ground. This, thoroughly accomplished, enables him to make low, short jumps which are gradually increased, first to longer and longer straight, low flights and then to higher and higher altitudes, until he has learned perfectly the use of all the controls, so that their manipulation becomes almost instinctive. Then he can attempt cross country and high altitude flights and the performance of all the tricks or stunts that go to make the expert aviator. But while this can be and has actually been done by the pioneers of aviation, or no man would be flying to-day, as no man was born a bird, on the other hand, it implies the courting of all the risks and dangers, often fatal, encountered by all those who made human flight an actual fact. Why, then, take such perilous chances when we have to-day plenty of expert instructors, who can teach us with the minimum danger? And it is the employment of an instructor, coupled with the type of

machine used, which gives us the other two systems of learning how to fly.

If a one-seat machine is used, as was the case before the two-seat machine was built, the instructor explains to the pupil the manipulation of the controls and mechanical devices of the motor and makes him execute the different motions, first with the machine stationary and then running up and down the field, until he has mastered the manipulation of the controls and motor mechanisms. This instruction is followed by the flying lessons, which are first explained and practically demonstrated by the instructor and then executed by the pupil. From the foregoing, it is easy to see that the pupil is always alone in handling the machine, and the corrections can be made only after the run on the ground or the flight is finished. This, undoubtedly, introduces an element of danger, which, to be minimized, implies a slow, gradual course of instruction with the consequent loss of time. While the sponsors of such method admit this fault, they claim in its favor the thorough confidence gained by the pupil, who, being left upon his own resources right from the beginning, will never have any trouble in solving his own problems at any time, no matter how hard they may be. While there is truth in this, the loss of time involved and the ever present source of irreparable injury or death certainly do not militate in its favor.

The quickest, best and, above all, safest method is the dual control system; that is, the use of a two-seat machine with duplicate controls, which can be used by two persons contemporaneously. This means that the pupil is never alone, but has always ready, to keep him out of trouble, the helping hand of his instructor, thus eliminating altogether the possibility of injury, due to faulty handling of the machine. The instructor first executes a given maneuver and the pupil, having the other set of controls at his disposal, feels all the motions made by the instructor and learns practically how to make them himself; then the instructor

allows him to repeat the same performance and in case he errs, he is instantly corrected, thus learning the proper way of handling the controls. Formerly, oral tuition was impossible during flight, due to the roar of the motor, and it was given before and after taking the air, but with the invention of the aërotelephone, even this fault has disappeared, and instructor and pupil are now in constant verbal communication. It is clear that this is by far the best method of teaching how to fly, and one which can hardly be improved as long as a noisy motor is used to furnish the motive power. Still, there are those who object to this system of tuition on the ground that it causes lack of confidence in the pupil, who, when left alone, doubts his own ability to handle the machine and finds himself in trouble, which may bring serious consequences. While, admittedly, it is human to become nervous in a case like this, on the other hand, the lack of confidence in the pupil is due more to the fault of the instructor, and to a certain extent to the pupil's, than to the system. If the instructor is really worthy of the name, he will not consider himself all the time the master of the situation, but will, after he has properly taught his pupil, allow him to handle the machine all by himself, being ready to come to the rescue only in case of an emergency; in other words, the instructor will take the part of a mere passenger and allow the pupil to be the pilot. This will increase, rather than decrease, the confidence in the pupil, because he will attempt all the different maneuvers with the assurance that if he goes wrong, no harm will befall him, and thus he will acquire a thorough knowledge of practical flying, which he will be ready to use at any time afterwards, be he in company or alone. If he were, instead, his self-instructor in a one-seat machine, would he be better off, would he dare execute any of the more difficult feats of daring, which were never taught him in a practical way? Evidently, in such a case, he has to take a chance, but so did others before him and often were maimed or killed. If he is his self-instructor,

he must proceed slowly, gradually, carefully; and this is exactly his part with the dual control system when he is left alone to fly, if his instructor did not teach him properly. Having practically mastered every phase of the evolutions through the guidance of the instructor, when the pupil takes the air alone, he has to go over one by one all the different manipulations, from the easiest to the most difficult, using good common sense in everything he does, if he wants to become a skillful aviator with the minimum of risk.

No matter what method used, the course of instruction is the same; that is, after having mastered an elementary, but thorough knowledge of the theory of flight, aëroplane construction and gas engines, the pupil is taught successively: taxying or grass cutting, elementary flying, stunts.

Taxying.—Taxying is the running of an aëroplane on the ground, and it has the object of familiarizing the pupil with the manipulation of the controls and motor devices. The machine used for taxying is either a heavy one unable to leave the ground or a regular machine with the motor so adjusted that the power developed is insufficient for flight.

In the case of the stick control, the manipulations, as we already know, are the following:

The stick pushed down causes the nose of the machine to go down; the stick pulled up causes the nose to go up.

The stick thrown to the right brings down the right side of the machine; the stick thrown to the left brings down the left side of the machine.

The foot rudder bar pushed to the right makes the machine turn to the right; the foot rudder bar pushed to the left makes the machine turn to the left.

With the wheel control, the only difference consists in turning the wheel to the right or left to accomplish the same result as when the stick is thrown to the right or left.

One very important point to impress on the mind of the pupil right from the beginning is to hold the control lever naturally, without an undue amount of force, and to handle

it lightly and slowly to acquire the proper touch, and control the machine in the right way. The motions of the controls during flight are almost imperceptible, especially with a very sensitive machine.

The controls are first operated by the pupil while the machine is stationary and then the manipulations are repeated with the machine in motion on the ground under its own power. Usually, the machine runs in a straight line from one end of the aviation field to the other, then the motor is throttled down or stopped and the machine turned around by hand to repeat the run; but sometimes the turn is made under power by manipulating the controls accordingly.

There is quite a difference between handling a machine on the ground and in the air: on the ground, there is to take into consideration the friction of the wheels and skid against the surface of the earth, which, especially in a badly made turn when the machine is under power, may cause the stripping of the tires, the buckling up of the wheels or the smashing of the undercarriage. There is also the possibility of breaking the wings by too steep a bank, which causes the wing tips to come in contact with the ground.

When the pupil becomes proficient in handling the controls, he is taken up in the air in a dual control machine and instructed in the art of flying.

Elementary Flying.—Here is the proper time to point out something really bad, which is possible only with the dual control method of instruction and which once more goes to show that it is not the system that is wrong, but the instructor—sometimes.

There are so-called expert instructors—and they may really be experts in aviation, but not by any means in psychology—who take an immense delight in frightening to the highest degree the poor pupil they take up for the first time. That this is a pernicious habit, which ought to be stopped or punished, if possible, is not necessary to empha-

size, but it is well to say that such a mischievous trick has sometimes had terrible consequences, which by themselves ought to be sufficient to warn the would-be silly teaser. In one particular instance, an instructor, who was taking up a pupil for his first flight, aimed the machine straight for a hangar, expecting to jump over it within the least distance—an easy thing to do for an expert aviator—but the pupil, thinking the instructor had gone crazy, unexpectedly took a hand in the matter and, frightened as he was, operated the controls with such a jerk that the aviator was unable to execute the necessary maneuver instantly and the machine went to smash itself against the hangar. This was the result of a mean trick on the part of a man, whose duty was just the opposite. But flying is safe if properly done, and a great deal in the improvement of the aëroplane is due to the war, which, horrible as it has been in all other respects, has given a great impetus to aviation, on account of the millions spent in perfecting the aëroplane as an engine of war.

For instruction purposes, when a single-seat machine is used, the best suited is the inherently stable; but with the dual control, it is better to use a machine with rather high power and sensitive controls.

In teaching his pupil, the instructor first executes himself the simplest manipulations and then tells the pupil to repeat them, correcting and advising him constantly with his viva voce instructions.

An instructor may, for instance, proceed by having the pupil perform the different maneuvers in the following order:

Straight flight. This will teach the pupil to hold the controls in the neutral position and experience the impossibility of keeping the machine level and on a straight course, due to the constantly changing currents of air, without the continuous manipulation of the controls.

Slight deviations from the straight course by pushing the rudder first to the left, which is easier of accomplishment, and then to the right, so that he may get used to turn both ways.

Slight climbs and descents to get used to the manipulation of the elevators.

Slight sideways motions to learn how to operate the ailerons.

Steeper climbs and descents.

Sharp left and right turns separately, involving the contemporaneous use of rudder and ailerons, as the machine must be banked in a sharp turn to prevent side slipping or skidding.

Left and right, right and left turns combined so as to describe a figure 8.

Slight climbing turns to combine the use of all the controls.

Gliding with motor throttled down and with the motor stopped.

Spiraling, or gliding and turning in the meantime in smaller and smaller circles with the power shut off.

Ascending from the ground.

Landing against the wind and across the wind.

Notice that landing is at the bottom of the list, being the most difficult thing to learn, while ascending immediately precedes it, as it is easier than landing, but harder than any aërial maneuver.

For each evolution in the air, the instructor teaches the pupil how to recover from it and bring the machine back to the normal position.

When the pupil can handle the machine perfectly well, without the presence of the instructor,—solo flying—then he will be taught advanced flying, which will classify him as an expert aviator.

Stunts.—The capital requirements of a stunting machine are strength and sensitiveness of controls. Of course, some of the stunts can be made with relatively slow and not very strong machines, but, on all occasions, it is better to remember the wise golden rule: Safety first!

Before proceeding to explain some of the most common stunts, it is well to go over a few things already treated, to

add and explain a couple of new terms and different functions of the controls.

The heavier and slower a machine, the less sensitive the controls.

Even in a speedy machine, the controls become less efficient if the speed slackens; the efficiency of the controls is, therefore, directly proportional to the speed.

As all water machines are heavier and slower than land machines, it follows that the manipulation of the controls differs, being more pronounced in the former than in the latter.

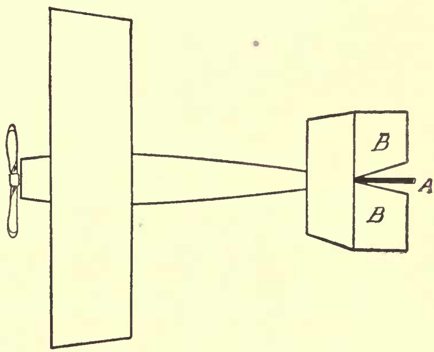


Fig. 82

In order to execute stunts safely, especially for the beginner, it is necessary to attain a good altitude, because whenever the machine is not in its normal, level, straight flight, there is loss of lift with a consequent sagging effect.

It is necessary to remember how the absence of the propeller torque, when the motor is stopped, affects a single-propeller machine, whether it has or not wash in or wash out.

In case of a very steep or vertical bank, the functions of rudder and elevators are completely reversed: the rudder *A* (Fig. 82) being then in a horizontal position will be used to bring the nose of the machine up or down; the elevators *B* being vertical serve to make the machine turn around.

In connection with steep banks, the terms used for the rudder are: top rudder and bottom rudder, irrespective of the fact that in either case it may be right or left rudder. For instance, if the machine is banked so that the right wing *A* (Fig. 83*a*) is down, then bottom rudder *B*, in this case,

would be equivalent to right rudder; but if the case is reversed, that is, if the machine is banked with the left wing

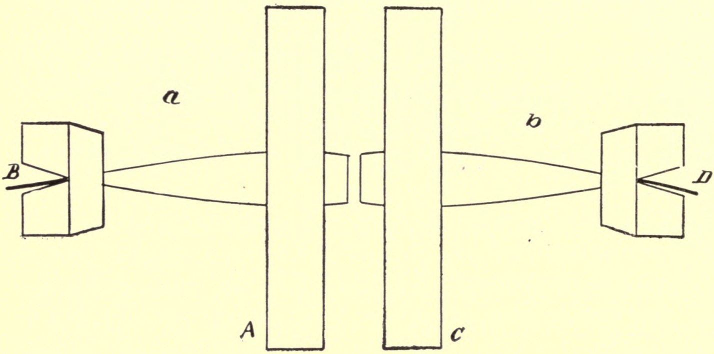


Fig. 83

C (Fig. 83) down, then bottom rudder *D* would mean left rudder.

If we first consider a machine in its normal flying position

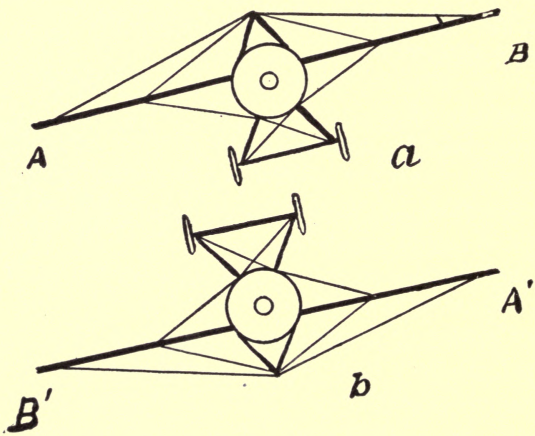


Fig. 84

(Fig. 84*a*), but with the wings banked, and then we consider it upside down (Fig. 84) and with the same bank, what

in the first case is considered as the lower wing A and the higher wing B, in the second becomes higher A' and lower B'. The bank is corrected in both cases with the same manipulation of the controls, the difference being that in the first case the wing would be depressed, while in the second it would be raised.

The above facts must be taken into consideration

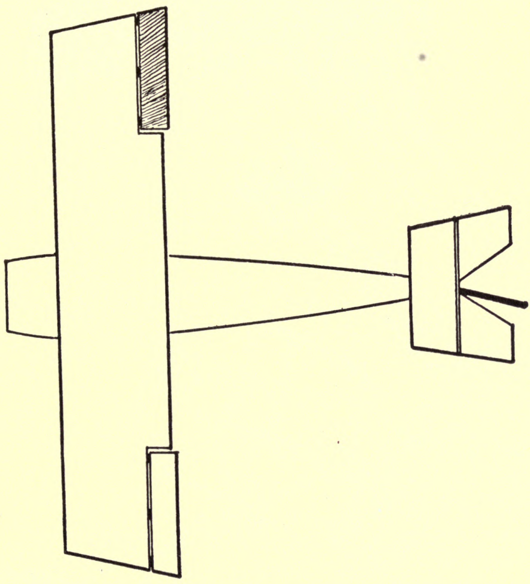


Fig. 85

whenever handling a machine either in regular flight or in stunts.

Now, let us take up some of the principal stunts.

Side slip (Fig. 85) is the sideways fall of an aëroplane due to over banking.

To side slip: bank steeply.

To recover from a side slip: move the control lever forward, throw lever towards the higher side of the machine until it is

level, neutralize the lever, pull the lever back gradually to flatten the course of the machine, neutralize the lever.

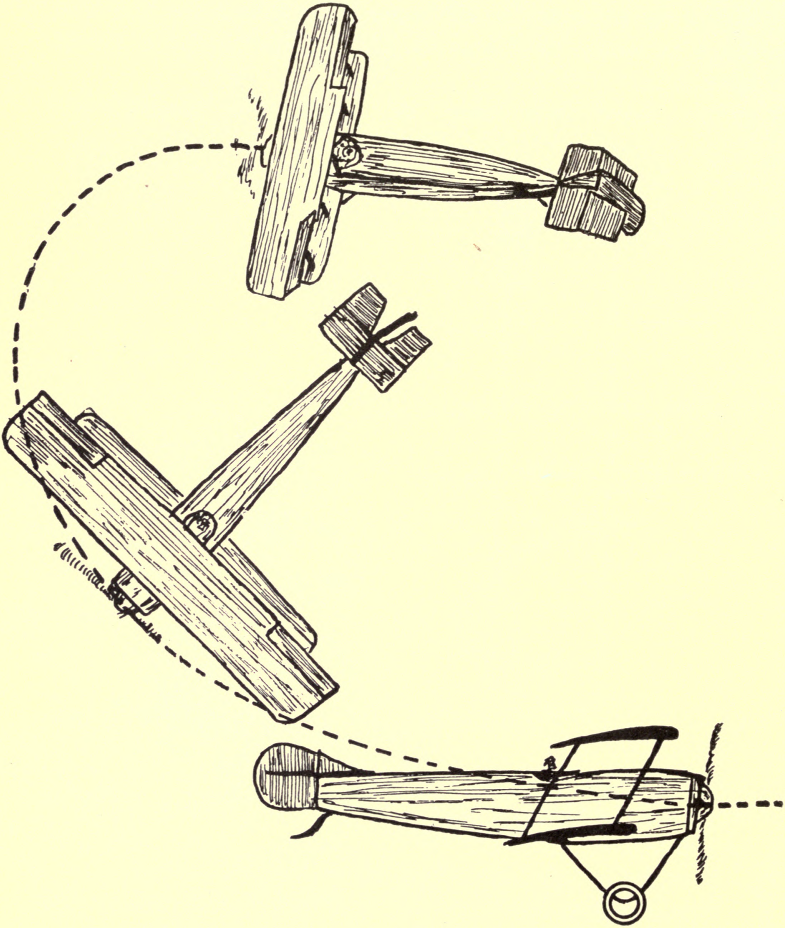


Fig. 86

Spin (Fig. 86) is a sideways whirling fall of an aëroplane due to underbanking in a turning motion. This gives us

the clue how to reproduce it voluntarily, but there is this important point to remember: when a spin is involuntary,

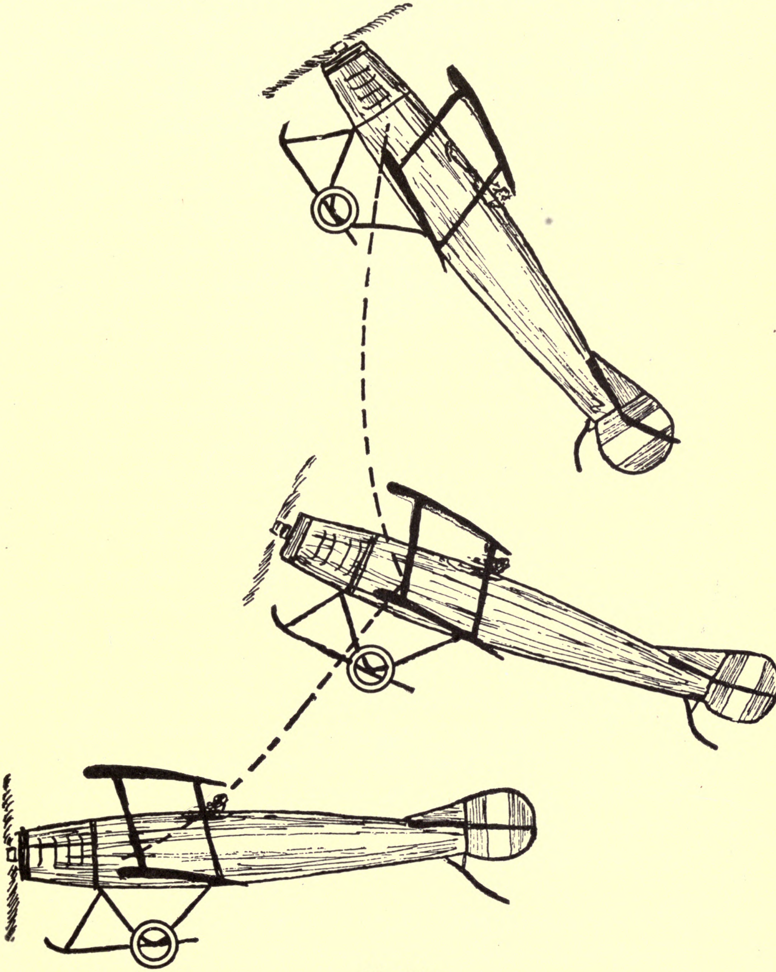
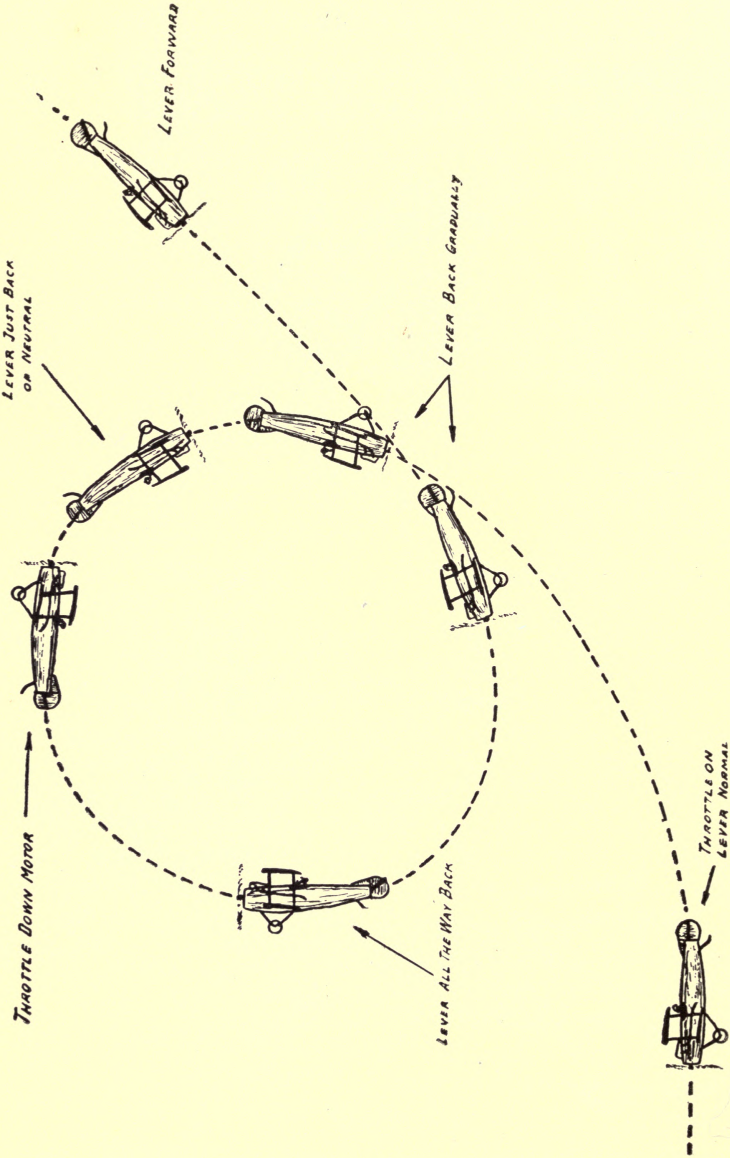


Fig. 87

the motor may or may not be running, and in case it is, it is wise to throttle it down to avoid undue speed and consequent



Lever Forward
Lever Just Back or Neutral
Lever Back Gradually
Throttle Down Motor
Lever All the Way Back
Throttle on Lever Normal

Fig. 88

stresses, while to reproduce a spin voluntarily, the first thing to do is to throttle down the motor.

To make a spin: throttle down the motor, put the rudder on sharply, pull back the control lever.

To recover from a voluntary or involuntary spin: neutralize the rudder, push down the control lever, pull back the lever gradually to flatten the course of the machine, neutralize the lever.

Tail slide (Fig. 87) is the falling of an aëroplane tail foremost, caused by a climb up to the stalling angle.

To produce a tail slide: pull the control lever back and climb steeply until the machine stalls, throttle down the motor. The machine falls tail foremost at first, but then the nose drops gradually and a dive begins.

To recover from a tail slide: pull back the lever gradually when the machine begins to dive in order to flatten its course, throttle on the motor.

Loop (Fig. 88) is a circle described by an aëroplane through the proper manipulation of the elevators.

The elevators must be operated properly to avoid a stall, and they must be assisted by the rudder and ailerons to keep the machine on a straight, level course to prevent a side slip, and by the timely throttling down of the motor to avoid a tail slide or too wide a loop.

To loop: climb at a good altitude, dive, pull back the control lever gradually until the machine is in a vertical position, pull the lever all the way back, throttle down the motor at the top of the loop, push down the lever just short of the neutral position as the machine begins to fall nose first, pull the lever gradually until the machine flattens out, throttle on the motor.

If a second loop is to be made, then the course of the machine is not flattened out at the end of the first loop, but it is allowed to dive until it acquires the necessary speed to repeat the looping evolution.

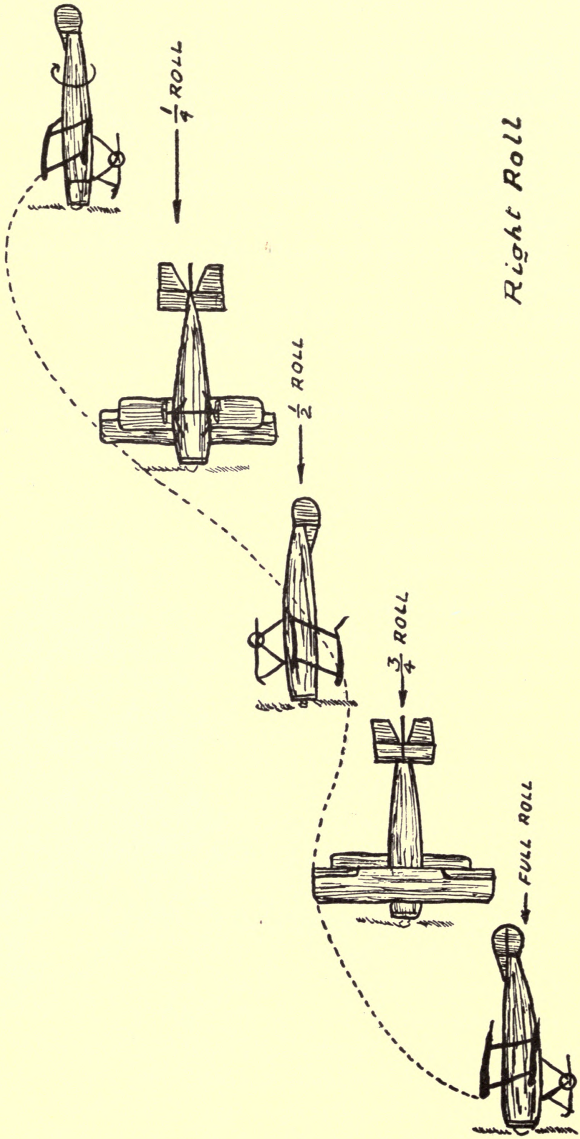


Fig. 89

Roll (Fig. 89) is the turning motion of an aëroplane around its longitudinal axis.

If the machine is to turn around its longitudinal axis, it is clear that this operation must be brought about by means of the ailerons. If the machine is banked and kept banked with the motor running, the continued operation of the ailerons will cause it to turn over and over, thus producing a screw-like action, which assists the forward motion, but as there is loss of lift, which tends to make the machine sag, it is necessary to aid this evolution by the occasional use of the rudder and elevators.

To make a complete left roll, the operation may be summarized thus: push down the control lever and then pull it up so that the machine first dives and then climbs, bank sharply until vertical, put on bottom rudder to assist the rolling motion, neutralize the rudder, pull back the lever to lower the nose a little when the machine is upside down, put on top rudder when the machine is again vertical, neutralize the rudder when the machine returns to its normal position.

This completes the roll. If more consecutive rolls are desired, the operation is repeated over and over.

The process to be followed to obtain a complete right roll differs only in the operation of the rudder, which, instead of being first bottom and then top rudder as in the present case, will be reversed: top and bottom rudder.

APPENDIX

AËRODYNAMICAL FORMULÆ AND CALCULATIONS *

My study of aëronautical science, or rather my battle with the text-books on aërodynamics, has been the longest, hardest mental struggle of my life.

Contrary to the rule for the mastery of knowledge, the more I studied, the less I knew; but, luckily, the less I knew, the more grew my desire to know. And I studied all the aëronautical books I could get hold of and written in the languages I understand, but the result was simply the twentieth-century reëstablishment of the ancient kingdom of Babylonia right between my brains, and an infernal dance of angles, sines, cosines, tangents and coefficients, which brought about such a tremendous pressure against the center of gravity of my brain as to threaten to unbalance it and to render myself fit for a straight flight right into an insane asylum. And this would certainly have been my fate, if a great scientist did not, unknowingly, come to my help.

This great scientist is the illustrious brother of our illustrious President, Sir Hiram Maxim.

In his valuable book, "Artificial and Natural Flight," I found the solution of the hard problem; not only for its sound teachings, but, also, for its emphatic approval of another book, which I had already studied and which, as all others, I was in doubt to follow, until so high an authority recommended it as "the most elaborate and by far the most reliable."

One thing that attracted my special attention in studying Sir Maxim's book was the fact that, in my trouble in regard to the study of aërodynamics, I was in good company, as he himself had the same experience when he first started to learn this famous science.

And not to alter the peculiar Maximian style, I will quote his own words.

* Lecture delivered before the Aëronautical Society of New York in February, 1911.

"During the last few years, a considerable number of text-books have been published. These have for the most part been prepared by professional mathematicians, who have led themselves to believe that all problems connected with mundane life are susceptible of solution by the use of mathematical formulæ, providing, of course, that the number of characters employed are numerous enough. When the Arabic alphabet used in the English language is not sufficient, they exhaust the Greek also, and it even appears that both of these have to be supplemented sometimes by the use of Chinese characters. As this latter supply is unlimited, it is evidently a move in the right direction. Quite true, many of the factors in the problems with which they have to deal are completely unknown and unknowable; still they do not hesitate to work out a complete solution without the aid of any experimental data at all. If the result of their calculations should not agree with facts, 'bad luck to the facts.'"

In another part of his book he says further,

"Some of the mathematicians have demonstrated by formulæ, unsupported by facts, that there is a considerable amount of skin friction to be considered, but as no two agree on this or any other subject, some not agreeing to-day with what they wrote a year ago, I think we might put down all of their results, add them together, and then divide by the number of mathematicians, and thus find the average coefficient of error."

But let us consider this controversy as a thing of the past, and and let us follow Sir Maxim's teachings and recommendations, which favor the use of Ritter von Loessel's formulæ.

The most important law governing aërial flight is based on the resistance of the air against a plane moving through it; and while all scientitsts agree that this resistance is proportional to the surface of the plane and to the square of its velocity, no two agree on the value of the coefficient of resistance, which has been baptized K.

This famous or infamous coefficient K, as a French writer calls it, or this ghost, as a member of our Society most appropriately named it, has been made to assume values ranging from 55 to 132 grammes to the square meter, which, as you see, shows very little difference. Anyhow, according to the latest edition and from experiments made on the Eiffel Tower, the value of the coefficient K is made equal to 80 grammes per square meter. So, barring

further editions and extras, we can take it for granted that we know the value of the coefficient of air resistance.

Now, then, if we call R the resistance of *calm* air against a plane moving perpendicularly through it, S the surface of the plane expressed in square meters, and V its velocity in meters per second, we obtain the formula:

$$R = K\,S\,V^2$$

I said *calm* air, because if the air has a motion of its own, v, then the formula will be:

$$R = K\,S\,(V \pm v)^2$$

And it will be $+v$ if the air moves in the sense of the motion of the plane, $-v$ if in opposite sense, and Ov if in calm air.

We will consider only this last case.

This, therefore, gives us the resistance of the air against a plane moving perpendicularly through it, but in this way we could not obtain sustentation, as the plane simply meets the air squarely in front of it and uses up all its energy in forcing it back, without producing useful work. What we need, instead, is that the plane be placed in such a position that the air give up some of its energy to the plane. Evidently, to produce this effect, we must place the plane in an inclined position, so that the air, meeting it at the forward edge, instead of being forced back, is compelled to flow away at the rear, producing useful work.

And here we are again up against another controversy, which rivals in importance that of the coefficient K; that is, the determination of the resistance of the air against an inclined plane, according to its angle of incidence.

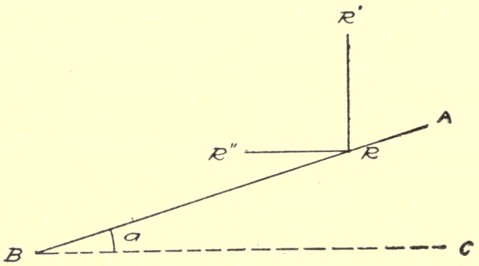
Without losing time in discussing Newton's formula, and the opinions given in favor and against it by aëro-mathematicians of the present day, we will use von Loessel's formula, which gives the resistance of the air against an inclined plane, moving through it, as being proportional to the sine of the angle of incidence. We will have, then, the formula:

$$Ra = K\,S\,V^2 \sin a$$

in which a is the angle of incidence.

Let us consider, now, the plane $A\,B$, moving through the air at an angle $A\,B\,C$.

The air will exercise against the plane a certain resistance R, which we will consider as resolved in two forces: R' and R'': the



90

first, R', tending to lift the plane, and the second, R'', resisting the forward motion.

The vertical component R' is the lift of the surface, and the horizontal component R'' is the drift.

The center of pressure of a plane surface is near the front at 0° of incidence, and it travels slowly backward as the angle increases, until it reaches the middle of the surface at 90°.

The formula which will enable us to find the center of pressure of a plane surface moving through the air at different angles of incidence is:

$$x = (0.2 + 0.3 \sin a)\, l$$

in which l is the length of the inclined side.

If we make $l = 1$, the formula will be:

$$x = 0.2 + 0.3 \sin a$$

If $\sin a = 0$,

$$x = 0.2 + 0.3 \times 0 = 0.2,$$

and if $\sin a = 1$,

$$x = 0.2 + 0.3 \times 1 = 0.5.$$

At 0°, then, the sine being O, we find that the center of pressure is at 2/10 from the front edge; and at 90° the sine being 1, the center of pressure is at 5/10 from the front edge; that is, at the center of figure, and, therefore, the center of figure and the center of pressure coincide.

Calling L the lift and D the drift, we may resolve the formula:

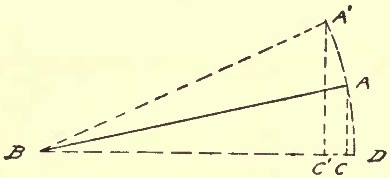
$$Ra = K\ S\ V^2 \sin a$$

into the two components:

$$L = K\ S\ V^2 \sin a \cos a$$
$$D = K\ S\ V^2 \sin^2 a$$

Sir Maxim uses different and practical methods to find out the lift and drift, but his considerations agree perfectly with von Loessel's formulæ.

Sir Maxim says that "the lifting effect will be just as much greater than the drift, as the width of the plane is greater than the elevation of the front edge above the horizontal." But he admits that "as the front edge A of the plane $A\ B$ is raised (A') its pro-



91

jected horizontal area $B\ C$ is reduced ($B\ C'$), and that if we consider the width of the plane as a radius, the elevation of the front edge will reduce its projected horizontal area just in the proportion that the versed sine $C\ D$ is increased ($C'D$). But, as for the sharpest practical angle of flight this reduction is about 2 per cent, while for the lower and more practical angles the reduction is considerably less than 1 per cent, this factor is so small that it may not be considered at all in practical flight."

Now, as in von Loessel's formulæ the lift is proportional to the product of the sine and cosine of the angle of incidence, and this product is a little smaller than the sine of the same angle, and the difference increases as the angle increases, we see that the small factor mentioned by Sir Maxim is taken into consideration by von Loessel, and the formula generalized for all angles.

This careful study of details by von Loessel explains the reason why Sir Maxim so highly commends his work.

Evidently, the lift is the weight that can be raised by the plane,

and the drift the resistance that must be overcome to obtain forward motion. If we, therefore, call W the weight of the plane and substitute it for L in the formula giving the lift, we will have:

$$W = K\,S\,V^2 \sin a \cos a$$

And if we want to express the drift in $H\,P$, we will obtain the following formula:

$$H\,P = \frac{K\,S\,V^3 \sin^2 a}{75}$$

because the formula of the drift,

$$D = K\,S\,V^2 \sin^2 a$$

gives us the drift in kilograms and to express it in $H\,P$, we must multiply it by the velocity, V, and divide by 75, as 75 kilogrammeters make one $H.\,P.$

By dividing the L or W by the $H\,P$, we will obtain the lift or weight per $H\,P$, that is,

$$\frac{W}{HP} = \frac{K\,S\,V^2 \sin a \cos a}{\frac{K\,S\,V^3 \sin^2 a}{75}} = \frac{K\,S\,V^2 \sin a \cos a\;75}{K\,S\,V^3 \sin^2 a} = \frac{\cos a\;75}{V \sin a} =$$

$$= \frac{75}{V} \times \frac{\cos a}{\sin a} = \frac{75}{V} : \frac{\sin a}{\cos a} = \frac{75}{V} : tg\,a = \frac{75}{V\,tg\,a}$$

The formula giving the lift and the formula of the drift expressed in $H\,P$ enable us to calculate any one of the elements entering in the consideration of horizontal flight, when we assume as known the other elements. But these formulæ are not final. Other and important considerations will modify them.

So far, we have been figuring on plane surfaces, but it is a well-known fact that arched surfaces possess greater lifting power, for the same amount of energy used, than plane ones. We must, therefore, know the coefficient of resistance of the arched surfaces, and multiply by it the value given by our formulæ. As this coefficient is not constant, but varies with the arching of the surface, we must determine it for the special form we want to use, and apply the value found to the formulæ giving the lift and drift. If

we call C this coefficient of curvature, our formulæ will become:

$$W = C\,K\,S\,V^2 \sin a \cos a$$

$$H\,P = \frac{C\,K\,S\,V^3 \sin^2 a}{75}$$

in which C is greater than 1.

Another consideration, which may be made to further alter these formulæ, is the knowledge that the area of the plane, found by multiplying its dimensions, is not really the effective area; that is, considering the actual surface area, we get less lifting power than we ought to. A plane one meter square will not lift one-tenth as much as one that is one meter wide and ten meters long. This is because the air slips off at the ends. In designing planes, therefore, we must not forget that area alone is not sufficient. The plane must have a certain length of entering edge in proportion to its width.

But although we know this to be a fact, no formula seems to be reliable enough at the present day to deserve any serious consideration. We can, therefore, do away with them all, and leave the formulæ as they are.

Let us consider, now, the formula giving the $H\,P$.

This formula gives us the means to determine the theoretical resistance to the forward motion of the plane. But in practice we know that using a motor of a given $H\,P$ to drive a propeller in order to obtain this forward motion, the propeller does not deliver all of the power transmitted by the motor, but only a certain percentage, according to the efficiency of the propeller used. The theoretical power, then, given by our formula, is cut down accordingly.

If we call $\frac{E}{100}$ the efficiency of the propeller, we will have to multiply by it the theoretical power given by our formula, and we will have, then:

$$E\,H\,P = \frac{C\,K\,S\,V^3 \sin^2 a}{75} \times \frac{E}{100}$$

Or, if we want to know what must be the $H\,P$ of the motor to use, so that, when reduced by the slip of the propeller, it will give us

the actual power required to drive our plane, we must divide the theoretical power by the efficiency of the propeller, and in this case the formula will be:

$$A\ H\ P = \frac{C\ K\ S\ V^3 \sin^2 a}{75} : \frac{E}{100} = \frac{C\ K\ S\ V^3 \sin^2 a}{75} \times \frac{100}{E}$$

But this is not all. Besides the loss through the slip of the propeller, we have to consider the head resistance of the framework of a flying machine, motor and aviator. And this is by no means a matter of little importance or easy calculation. It all depends on the shape, cross section and inclination of the different parts used in building the machine. It is, therefore, impossible to give specific rules for the computation of the head resistance. All we can say is that it must be calculated separately for every machine, and that to be reduced to the least, we must avoid plane surfaces perpendicular to the direction of motion of a flying machine, and use in the construction of the framework those shapes best calculated to reduce head resistance. For each shape and cross section of bar, there is a special coefficient, which must be applied for each special case. Round bars, for instance, or oval, bipointed bars, set with one of the points to the direction of motion, offer less resistance than others differently shaped.

Anyhow, whatever this head resistance may be, the power necessary to overcome it must be found out and added to that already calculated, and in this way we will get the sum total of the actual power required to obtain horizontal flight.

In other words, after we have calculated the theoretical power required to drive our plane through the air, we must find out the loss of power through the propeller slip and head resistance, and increase accordingly the $H\ P$ required.

If we suppose to have calculated the surface area of the head resistance, *Sh*, and consider it as a plane surface moving perpendicularly in the direction of motion of the flying machine, we will have the formula:

$$R_h = K\ S_h\ V^2$$

or expressed in $H\ P$:

$$R_h\ H\ P = \frac{K\ S_h\ V^3}{75}$$

which must be added to the actual $H\ P$ found before, that is,

$$A\ H\ P = \frac{C\ K\ S\ V^3 \sin^2 a}{75} \times \frac{100}{E}$$

to obtain the total $H\ P$ required to accomplish horizontal flight, so that the total $H\ P$ will be:

$$T\ H\ P = \frac{C\ K\ S\ V^3 \sin^2 a}{75} \times \frac{100}{E} + \frac{K\ S_h\ V^3}{75}$$

Considering the expression of the formulæ giving the drift and lift, we see that the drift increases as the square of the sine of the angle of incidence, and the lift increases as the product of the sine and cosine. This last product is a maximum when the angle is 45°, but taking into account the drift, we find that the best lift drift ratio is really attained for angles smaller than 45°. At 45°, as sin = cos, sin × cos = sin², and, therefore, $L = D$.

As the practical angles of flight are small, it follows that the drift is much smaller than the lift; and as the lift is in reality the weight of the aëroplane, or, in other words, the force of gravity, we see that the power required to raise an aeroplane is much smaller than the force of gravity. The aëroplane, therefore, is very economical in regard to power, compared with the helicopter or ornithopter, as these machines, to leave the ground, must produce first of all a vertical force powerful enough to overcome that of gravity, and this without considering the power lost in consequence of the extreme fluidity of the air.

Sir Maxim in this regard says:

"Recently there has been a great deal of discussion regarding the comparative merits of the aëroplane system and the helicopter. Some condemn both systems and pin their faith to flapping wings. It has been contended that the screw propeller is extremely wasteful in energy, and that in all nature neither fish nor bird propels itself by means of a screw. As we do not find a screw in nature, why then should we employ it in a machine for performing artificial flight? Why not stick to nature? In reply to this, I would say that even nature has her limits, beyond which she cannot go. When a boy was told that everything was possible with God, he asked: 'Could God make a two-year old calf in five minutes?' He was told that God certainly could. 'But,' said the boy 'would

the calf be two years old?' It appears to me that there is nothing in nature which is more efficient, or gets a better grip on the water than a well-made screw propeller, and no doubt there would have been fish with screw propellers, provided that Dame Nature could have made an animal in two pieces. It is very evident that no living creature could be made in two pieces, and two pieces are necessary if one part is stationary and the other revolves; however, the tail and fins very often approximate to the action of the propeller blades; they turn first to the right and then to the left, producing a sculling effect which is practically the same. This argument might also be used against locomotives. In all nature, we do not find an animal traveling on wheels, but it is quite possible that a locomotive might be made that would walk on legs at the rate of two or three miles per hour. But locomotives with wheels are able to travel at least three times as fast as the fleetest animal with legs, and to continue doing so for many hours at a time, even when attached to a very heavy load. In order to build a flying machine with flapping wings, to exactly imitate birds, a very complicated system of levers, cams, cranks, etc., would have to be employed and these of themselves would weigh more than the wings would be able to lift."

In order to apply to a practical case the formulæ given, let us suppose that we want to build an aëroplane.

We must assume the knowledge of some of the values of the formulæ to calculate the other values.

In the formula giving the lift:

$$W = C\,K\,S\,V^2 \sin a \cos a$$

we know only the value of the coefficient K, and we may know that of C, if we give to our planes a curvature whose coefficient is known, otherwise we have to find it out practically ourselves. Supposing, then, that we have the value of C, we need to know at least three more values, before we can determine the fourth.

Now, we usually know the weight of our machine and the angle of incidence, which we choose as best; what we must determine, therefore, is either the surface, to find out the velocity, or the velocity, to figure out the surface.

It is up to us, then, to set out the value of the one or the other, according to our own wish in regard to the speed of the machine.

If we increase the speed, we diminish the surface, and vice versa. But, of course, this is by no means arbitrary, and we must have an idea right from the beginning, of what we want, otherwise we will get the data of a machine which theoretically fulfills our wants, but practically is an impossibility.

If we started to figure out the weight of the machine, we must have considered its dimensions in regard to its approximate surface, so as not to compel us at the end to alter completely its dimensions and consequently its weight. So it is, too, in regard to the velocity and load, as we must figure on the strength of the material in regard to the stress that the framework can stand without a breakdown. The same rule holds in regard to the proportion of the weight to the power of the motor.

If we have started without an approximately correct idea of what our machine is going to be, we might find out at the end that either the surface is too small, or the machine is too weak, or the motor is too heavy for the power it gives.

In this case, we would be in the same position of the early experimenters, who had to spend years before they could find out the proper data to build a successful machine.

The best thing to do, then, is to study the approved types of existing machines, and vary their proportions according to our special case.

Anyhow, more than one calculation is always necessary to vary our erroneous assumptions, before we get the final correct result.

Let us see, now, how from our fundamental formula giving the W, we can derive the value of all the other unknown quantities in it contained.

From the formula:

$$W = C\,K\,S\,V^2 \sin a \cos a$$

we have:

$$S = \frac{W}{C\,K\,V^2 \sin a \cos a}$$

$$V = \frac{W}{\sqrt{C\,K\,S \sin a \cos a}}$$

$$\sin a \cos a = \frac{W}{C\,K\,S\,V^2}$$

For the last formula, as we have no tables giving the product of sines by cosines, we will have to use the knowledge that the sine by the cosine of an angle is equal to one-half the sine of an angle double. Therefore, after we find the product sin by cos, we have to double it, to know the sine of the angle double; then we find, in the tables of the natural functions of angles, which angle in degrees corresponds to this sine, and we divide the degree by two, to arrive at the angle we are looking for. For this reason, the formula may be expressed:

$$\sin 2a = \frac{2\,W}{C\,K\,S\,V^2}$$

and, if found convenient, the same substitution may be made in all the other formulæ.

Suppose, now, that for our machine we want to use a 30 H. P. motor weighing 65 Kgs., that the plane surface is 25 square meters and inclined at an angle of 7°, that the framework weighs 125 Kgs. according to our calculations in regard to the strength of the material chosen, that the coefficient of curvature is 1.25, and, finally, that the aviator weighs 60 Kgs. The total weight of the machine will be, then: $65 + 125 + 60 = 250$ Kgs.

Knowing the weight, the surface and the angle of incidence, we can find the velocity from the formula:

$$V = \sqrt{\frac{W}{C\,K\,S \sin a \cos a}}$$

as we have all the numeric values of the quantities which determine the value of V; that is, $W = 250$, $C = 1.25$, $K = 0.080$, $S = 25$, sin angle $7° = 0.1219$ and cos angle $7° = 0.9925$. Therefore:

$$V = \sqrt{\frac{250}{1.25 \times 0.080 \times 25 \times 0.1219 \times 0.9925}} = 28$$

The velocity of our aëroplane will be, then, 28 meters per second. Found the value of V, we can find the $H\,P$, that is:

$$H\,P = \frac{C\,K\,S\,V^3 \sin^2 a}{75} = \frac{1.25 \times 0.080 \times 25 \times \overline{28}^3 \times \overline{0.1219}^2}{75} = 10.82$$

Supposing that the efficiency of the propeller we want to use is $\frac{80}{100}$, the actual $H\ P$ will be:

$$A\ H\ P = 10.82 \times \frac{100}{80} = 13.52$$

If we consider the surface area of the head resistance as equivalent to a plane of 0.50 square meters moving orthogonally through the air, then:

$$R_h = \frac{K\ S_h V^3}{75} = \frac{0.080 \times 0.50 \times \overline{28}^3}{75} = 11.70\ H.\ P.$$

Attention should be paid to the fact that only one-half square meter of surface of head resistance requires about as much power as 25 square meters, or 50 times as much surface, set at the angle of 7°. This tells clearly the enormous power required to drive the framework alone of the machine.

The total $H\ P$ will be, therefore:

$$T\ H\ P = 13.52 + 11.70 = 25.22$$

As our motor is 30 $H\ P$, we have a good margin left, and, consequently, the machine will fly.

And now that our aëroplane is ready to take the air, let me jump in and fly away.*

* The formula giving the $T\ H\ P$ could be simplified into

$$T\ H\ P = \frac{K\ V^3\ (100\ C\ S \sin^2 a + Sh\ E)}{75\ E}$$

but it was not, in order to show all the different data entering in the final calculation.

The aërodynamical formulæ given in the metric system may be reduced in British units by making: $K = 0.003$, S = area in square feet, V = velocity in miles per hour, W = pounds and $H\ P$ = 33,000 foot pounds per minute. Thus, the formulæ visibly changed would be those in which enters the computation of the horsepower, that is,

$$H\ P = \frac{K\ S\ V^3 \sin^2 a}{33{,}000}$$

and following; the others remaining the same algebraically and differing arithmetically only relatively, according to the values substituted for the letters in the application of either the metric or the British system of measurement, but being the same in absolute value.

DEFINITIONS

Acetone is a limpid, colorless, volatile liquid of penetrating ethereal odor and pungent taste, obtained from the products of the destructive distillation of wood or by heating calcium acetate. It is a useful solvent for gums, resins and fats.

Aërodrome is the ground used for the practice of aviation.

Aëroplane is a power-driven aircraft sustained in flight by the reaction of the air against wings set at an angle with the line of motion. It is distinguished as monoplane and multiplane, according to the number of superposed wings used; the biplane, triplane, etc., being particular cases of the multiplane.

Aileron is a controlling plane hinged horizontally to the rear of a wing toward the tip and used for lateral control.

Air speed meter is an instrument which measures the velocity of the air and, as a consequence, that of an aëroplane when installed on it.

Algebra is the science of numbers expressed by letters and symbols.

Equation is the expression of the condition of equality between two algebraic quantities or set of quantities, the sign = being placed between them.

Formula is a rule or principle expressed in algebraic language.

From the above definitions, it follows that the aërodynamical formulæ are equations. What we want to know, then, is how to solve an equation, in order to find out the values of the different quantities expressed by the letters of the formulæ.

In arithmetic, we express quantities by means of numbers; in algebra, we use letters, which give us a better opportunity to generalize a given rule. Suppose, for instance, that we want to express in a general way how to find the surface area of a rectangle. Geometry teaches us that this is accomplished by multiplying one of its dimensions by the other. To solve the problem arithmetically, then, we have to know the value of the two dimensions expressed

in numbers, and if these two numbers are 5 and 2, we will multiply one by the other and say:

$$5 \times 2 = 10$$

Algebraically, instead, we do not need to know these numeric values, but we will call one of the dimensions A, for instance, the other B and the surface area S, and we will say that

$$S = A \times B, \text{ or simply: } S = A\ B,$$

as, in algebra, the absence of a sign between letters or one number and letters means multiplication.

This is the general way we express in our case the surface area of a rectangle, and we call it a formula. To solve this formula or equation arithmetically, we have to know the numeric values of A and B, substitute them respectively for the letters and multiply one by the other. If $A = 6$, $B = 3$, then:

$$S = 6 \times 3 = 18$$

Analyzing what we have done, we see that to find the value of S, we need to know the value of A and B, that is, out of three quantities of a formula, we must know two to find out the third. Generalizing this special case, we will say that in order to find the value of one quantity of a formula, we must know the value of all the other quantities.

To solve an equation, we must know the following rules:

We can add or subtract, multiply or divide by, the same number both members of an equation without altering the equality.

Let us explain this arithmetically, first. If we have the expression:

$$5 + 4 + 1 = 6 + 2 + 2$$

or, which is the same:

$$10 = 10$$

we can add to each member the same number, say, 5, without altering the equality; in fact, it will be:

$$10 + 5 = 10 + 5$$

In the same way, we can subtract the number 3, and we will have:

$$10 - 3 = 10 - 3$$

Or, multiplying by 4:

$$10 \times 4 = 10 \times 4$$

And, finally, dividing by 2:

$$\frac{10}{2} = \frac{10}{2}$$

In the same way we can raise to power, or extract the root of, both members of an equation without altering its equality, as these two last cases really amount to special instances of multiplication and division. So, it will be:

$$10 = 10;\ 10^2 = 10^2, \text{ that is, } 10 \times 10 = 10 \times 10.$$
$$16 = 16;\ \sqrt{16} = \sqrt{16}, \text{ that is, } 4 = 4.$$

Using the same process algebraically, we will have the following equations:

If	$a = a$
adding b,	$a + b = a + b$
subtracting c,	$a - c = a - c$
multiplying by d,	$a\,d = a\,d$
dividing by e,	$\frac{a}{e} = \frac{a}{e}$

raising to power, $a^2 = a^2$, $a^3 = a^3$, $a^n = a^n$

extracting the root, $\sqrt{a} = \sqrt{a}$, $\sqrt[3]{a} = \sqrt[3]{a}$, $\sqrt[n]{a} = \sqrt[n]{a}$

Suppose now that we have this equation:

$$a - b + c = d + e$$

and that we add the quantity b to both members, that is:

$$a - b + c + b = d + e + b$$

In the first member of this equation, we see that there is the same quantity, b, added and subtracted in the meantime. As the result would be zero ($+ b - b = 0$), we can suppress it and have:

$$a + c = d + e + b$$

Comparing this equation with the first one, we see that the term b, which was in the first member with a negative sign ($-$), passed to the second member with a positive sign ($+$).

If we now subtract from both members of the equation

$$a - b + c = d + e$$

the quantity c, we will have:

$$a - b + c - c = d + e - c$$

As $+ c - c = 0$, it will be:

$$a - b = d + e - c$$

that is, $+ c$ in the first member became $- c$ in the second.

If we have the equation:

$$a\,b = \frac{c}{d}$$

and multiply all by d, we will have:

$$a\,b\,d = \frac{c}{d}\,d$$

or

$$a\,b\,d = c\frac{d}{d}$$

as $\frac{d}{d} = 1$, therefore:

$$a\,b\,d = c \times 1, \text{ that is: } a\,b\,d = c$$

We see, then, that the quantity d, which was in the second member as a divisor, passed to the first member as a multiplicator.

And, finally, if we have the equation:

$$a\,b = c$$

and divide all by b, we have:

$$\frac{a\,b}{b} = \frac{c}{b}, \qquad a\frac{b}{b} = \frac{c}{b}, \qquad a \times 1 = \frac{c}{b}, \qquad a = \frac{c}{b}$$

That is, b from multiplicator in the first member became divisor in the second.

We will say, therefore, that we can pass one term from one member of an equation to the other by changing its sign without altering the equality.

We understand, now, why from our aërodynamical formula:

$$W = C\,K\,S\,V^2 \sin a \cos a$$

we obtain the values of each quantity by passing the others from multiplicators in one member to divisors in the other, and in the case of the velocity by extracting the square root from both members.

Altimeter is a modified barometer used for measuring height.

Anemometer is an instrument for measuring the force and velocity of the wind.

Angle of attack is the angle formed by the chord of the wings with the line of flight when the aëroplane climbs or descends.

Angle of sweepback is the angle formed by the leading edge of a wing with the lateral axis of an aëroplane. Best climbing angle is approximately halfway between the maximum and optimum angles.

Flying angle of incidence is the angle formed by the neutral line of a plane with the line of flight. It is positive when formed above the line of flight; negative, when formed below the line of flight; zero, when the neutral line is parallel with the line of flight.

Gliding angle is the angle of attack of an aëroplane descending by force of gravity.

Lateral dihedral angle is the angle formed by two wings when they are tipped upward.

Longitudinal dihedral angle is the angle formed by the prolongation of the chord of the wings with the prolongation of the chord of the horizontal stabilizer. If the angle is formed by the prolongation of the neutral lines, it is the flying longitudinal dihedral angle; if formed by the prolongation of the chords, it is the rigger's longitudinal dihedral angle. Rigger's angle of incidence is the angle formed by the chord of a plane with the line of thrust.

Maximum angle of incidence is the greatest angle at which, with a given power, surface and weight, horizontal flight can be maintained.

Minimum angle of incidence is the smallest angle at which, with a given power, surface and weight, horizontal flight can be maintained.

Optimum angle of incidence is the angle at which the lift drift ratio is the best.

Antidrift wire is a wire which acts against the tension of a drift wire. There are two kinds of antidrift wires: center section and frame antidrift wires.

Aspect ratio is the proportion of the span to the chord of a plane.

Aviation is the branch of aëronautics that treats of the gasless aircraft.

Banana oil or varnish is a mixture of acetone and amylacetate with liquid celluloid, having a marked banana-like odor.

Bank is to tilt an aëroplane sideways when turning.

Barograph is a self-registering barometer, which gives a continuous graphic record of the fluctuations of the atmospheric pressure.

Barometer is an instrument which measures the pressure of the atmosphere.

Bay is a compartment in the fuselage or in the wings of a multiplane.

Bending is the combination of the compression and tension stresses.

Blow torch is a lamp burning gasoline, forced by air pressure through a hot, holed tube, to gasify and mix it with air and produce an intensely hot, blue flame.

Cabane is a metallic framework to which are attached the landing wires of the wings of a monoplane or the upper wings of a multiplane that has no center section.

Camber is the curvature of a plane.

Cap strip is the flange of a rib.

Castellated nut is a nut with grooves in its upper face to receive a cotter pin.

Cavitation is the rarefaction of air produced in the space immediately in the rear of swiftly revolving propeller blades, due to the rapid cleavage of the air by the blades and the relatively slow action of the air in closing in behind the moving blades.

Cellulose is the principal component of all vegetable tissues. Cotton and filter paper are almost pure cellulose.

Center line of pressure is a line running from tip to tip of a wing and through which all the air forces acting on the wing may be said to act.

Center of gravity of a body is the point about which all its parts are balanced.

Center of lift is the point of application of the resultant of all the lifting forces of an aëroplane.

Center of pressure is the point at which the whole amount of

pressure may be concentrated with the same effect as when distributed.

Center of resistance is the point of application of the resultant of all the forces of the passive drift acting against the different parts of an aëroplane.

Center of thrust is the point of application of the thrust of the propeller.

Center section is the central structure which connects the upper wings of a multiplane.

Centrifugal force is the reaction of a body against a force that is causing it to move in a curved path.

Centripetal force is a force drawing a body toward the center around which it revolves.

Chord is the straight line drawn from the leading to the trailing edge of a plane.

Clevis pin is a rivet with a hole in the point for the passage of a cotter pin.

Cockpit is the compartment of the fuselage which contains the pilot's seat.

Compass is an instrument by means of which the directive magnetic force of the earth upon a freely suspended magnetic needle is utilized to determine horizontal directions in reference to the north and the other cardinal points.

Compression is the stress which tends to crush a body.

Control lever is a wooden stick or metallic tube to which are attached the cables of the ailerons and elevators for controlling their motions.

Controlling plane is a plane designed to control mechanically the motions of an aëroplane longitudinally, laterally or directionally. There are three kinds of controlling planes: elevators, ailerons and rudder.

Cotter pin is a split key made by bending a half round wire with the flat face inside, so as to form an eye at the bend and bring together the two halves or leaves, which thus make a round wire open in the middle. It is inserted in the hole of a clevis pin to lock it safely in place by spreading out the leaves or to lock the nut of a bolt provided with an apposite hole at its threaded end.

Decalage is the difference in the angle of incidence of any two planes in the same machine.

Disk wheel is a wheel stream-lined by covering its spokes with cone-shaped sheets of metal, celluloid or doped fabric.

Dope is a solution of cellulose nitrate or acetate and banana oil used to paint the fabric covering of aëroplanes to make it taut and airproof.

Dowel is a round stringer.

Drift is the horizontal component of the air resistance against a plane.

Active drift is the drift of the lifting planes.

Passive drift is the drift of all the other parts of an aëroplane.

Total drift is the entire resistance of the air against the machine in flight and includes the active drift, the passive drift and the skin friction.

Drift meter is an instrument which indicates the leeway of an aëroplane. It consists of a telescope, containing a series of parallel hairs with a graduate scale and pointer, mounted vertically to enable the pilot to look down upon the ground directly beneath him. By turning the telescope so that the hairs are parallel with the line of motion, indicated by roads, rivers or other landmarks, the exact leeway or drift of the aëroplane is measured by the needle of the indicator.

Drift wire is a wire which supports some part of a machine against the drift during flight. There are three kinds of drift wires: the wing drift wires, which run from the nose plate to the wings; the center section drift wires, which go from the upper longerons to the front struts of the center section; and the frame drift wires, which are attached between compression ribs inside of the frame and are hidden from view by the fabric covering.

Droop is the increase in the angle of incidence of the ailerons and elevators to compensate the decrease which occurs in flight owing to the resistance of the air.

Eddy is a current of air moving in a direction contrary to the main current.

Efficiency of construction is the ratio of the lifting surface to the passive drift surface of an aëroplane. (If the lifting surface is 200 square feet and the passive drift surface is 10 square feet, the efficiency of construction is 200 : 10 = 20.)

Elevator is a controlling plane hinged horizontally to the rear

of the horizontal stabilizer of a machine to direct it upwards or downwards.

Empennage is the tail of an aëroplane.

Equilibrium is the state of balance produced by the mutual counter action of two or more forces. Equilibrium is characterized by three phases: stable, unstable and indifferent or neutral. A body is in a state of stable equilibrium when, being disturbed, it tends to return to its previous position; in this state, the center of gravity of the body is in its lowest possible place. A body is in a state of unstable equilibrium when, being disturbed, it tends to move away from its previous position; in this state, the center of gravity of the body is in its highest possible place. A body is in a state of indifferent or neutral equilibrium when it keeps its balance independently of the position it is put in; in this state, the center of gravity of the body is at its center.

Extension or overhang is the lateral extension of an upper wing beyond the span of a lower wing of a multiplane.

Factor of safety is the ratio of the stress of collapse of a body to the maximum stress it is called upon to withstand.

Fair lead is a short metallic tube with funnel-shaped ends through which runs a cable.

Fairing is the additional material used to stream-line a body.

Ferrule is a short tubular coupling used for locking a solid wire loop.

Fineness is the ratio of the length to the width of a stream-lined body. It is directly proportional to the velocity.

Fitting is a metallic fixture which connects the joints of different pieces of the framework of a machine.

Flying boat is a hydroaëroplane with a hull in the place of a fuselage.

Flying wire is a wire attached to a point of a wing to prevent it from breaking when the machine is in flight.

Flux is a substance that promotes the fusion of metals, prevents their oxidation under the action of heat and cleans their surface.

Foot rudder bar is a wooden bar to which are attached the rudder control wires.

Fuselage is the stream-lined main body of an aëroplane to which all the other parts are attached.

Gap is the space between two planes, measured from chord to chord.

Hangar is an aëroplane shed.

Helicopter is a machine intended to fly by means of horizontal screw propellers.

Horizontal equivalent is the horizontal projection of a body.

Horizontal stabilizer or fixed tail plane is a plane bolted on the upper tail end of the fuselage to give inherent longitudinal stability to an aëroplane.

Hydroaëroplane is a machine with pontoons attached to the undercarriage to enable it to rest on and rise from water.

Hydrochloric acid or muriatic acid is a colorless, corrosive, pungent gas, exceedingly soluble in water. What is commonly known as hydrochloric acid is a strong aqueous solution, colored yellow by impurities. It is generally made by the action of strong sulphuric acid on common salt.

Hydroplane is a flat bottomed, high-powered motor boat, which skims at a high speed on the surface of the water.

Inclinometer is a curved spirit level which indicates the degree of inclination of an aëroplane with the horizontal. There are two kinds of inclinometers: one determines the angle of attack; the other, called laterometer or bank indicator, the angle of bank.

Inertia is that property of matter by virtue of which it persists in its state of rest or of uniform motion in a straight line unless it is acted upon by some external force.

Interference is the detrimental effect produced in the gap by the rush of air or wash, which disturbs both the rarefaction of the top camber of the lower wing and the compression of the lower camber of the upper wing.

Inspection cover is an accessible stream-lined cover, fastened to the upper longerons by hinges on each side, which can easily be removed to inspect the control and fuselage wires.

Keel surface is the total side elevation surface of a machine. (Body, wings, struts, wires, wheels, etc.)

King post is a short mast bolted to a plane for the attachment of cables or wires.

Landing wire is a wire attached to a point of a wing to prevent it from breaking when the machine lands or stands on the ground or when the wing is subjected to a reversal of load.

Leading or entering edge is the front edge of a plane.

Level is an instrument used to determine a horizontal line.

Lift of an inclined, cambered plane is the vertical component of the air resistance against the lower camber, enhanced almost to its full power by the rarefaction on the upper camber, which facilitates the lifting force, owing to the difference in the density of the two currents of air flowing along the surfaces of the plane.

Lift drift ratio is the proportion of lift to drift. Considering the lifting planes alone, it is the ratio of lift to drift; considering the entire machine, it is the ratio of lift to total drift.

Line of flight is the direction in which flight takes place. It is referred to the horizontal, and, therefore, the line of flight is the horizontal.

Longeron is a long wooden piece running longitudinally in the fuselage.

Loop is the doubling of a wire in such a way as to form an eye.

Margin of lift is the height to which an aëroplane can rise in a given time and from a given altitude.

Margin of power is the power available above that necessary to maintain horizontal flight.

Metric system is the method of measurement based on the meter, which theoretically is the $\frac{1}{10{,}000{,}000}$ part of the quadrant of a terrestrial meridian, and actually is the length of a bar of platinum designed to represent that dimension.

The metric system removes the confusion arising out of the excessive diversity of weights and measures prevailing in the world, by substituting in place of the arbitrary and inconsistent systems actually in use, a single one constructed on scientific principles and resting on a natural and invariable standard.

The unit of length is the meter (30.37 inches); the unit of surface, the square meter (1550 square inches); the unit of capacity, the liter (1.0567 quarts); and the unit of weight, the gram (15.432 grains troy).

Each unit has its decimal multiples and submultiples; that is, weights and measures ten times larger or ten times smaller than the unit of the denomination preceding.

The prefixes denoting multiples are derived from the Greek language, and are: *deca*, ten; *hecto*, hundred; *kilo*, thousand; and *myria*,

ten thousand. Those denoting submultiples are from the Latin and are: *deci*, tenth; *centi*, hundredth, and *milli*, thousandth.

The unit of itinerary measure is the kilometer or 1000 meters (0.62138 mile), and the unit of commercial weight is the kilogram or 1000 grams (2.205 lb. avoirdupois).

The meter is divided in ten decimeters, the decimeter in ten centimeters, the centimeter in ten millimeters; just as the dollar is divided in ten dimes, the dime in ten cents, the cent in ten mills; so that it is just as easy to figure out in meters as it is in dollars.

The abbreviation of kilometer is Km.; square kilometer, Km^2.; kilogram, Kg.; meter, m.; decimeter, dm.; centimeter, cm.; millimeter, mm.; square meter, m^2., the exponent being used for its submultiples; cubic meter, m^3., using the same exponent for the submultiples.

Momentum is the force of motion acquired by a moving body by reason of the continuance of its motion. It is measured by the product of the mass by the velocity of the body.

Monocoque is a tractor fuselage entirely stream-lined with three-ply veneer, without longerons, struts or wire bracing.

Nacelle is the short body of a pusher aëroplane.

Neutral line is an imaginary line, drawn from the trailing edge through the width of a wing, parallel to the line of flight when the wing has no lift.

Nose dive is a nose first plunge of an aëroplane.

Nose plate is a specially shaped steel sheet which connects the front ends of the longerons.

Ornithopter is a machine intended to fly by means of flapping wings.

Outriggers are long pieces of wood which support the tail of a pusher machine.

Parabola is a curve formed by the intersection of the surface of a cone with a plane parallel to one of its sides.

Parabolic curve is a curve resembling a parabola.

Plane is a wooden and metallic framework covered with fabric.

Plumb line is a string with a weight or bob attached to one of its ends, used to determine a vertical line.

Pontoon is a light, airtight, boat-like float.

Projected propeller surface is the surface projection of a propeller into a plane perpendicular to its axis.

Propeller axis is the straight line about which the propeller revolves.

Propeller gap is the distance between the helicoidal paths of two consecutive blades.

Propeller pitch is the distance through which a propeller would advance in one revolution, if it moved in an unyielding medium. This is the theoretical pitch. The effective pitch is the distance actually traveled by the propeller in one revolution. The pitch is constant when the angle of the blades varies; it is varying, when the angle is constant.

Propeller pitch angle is the angle at which a propeller blade is set.

Propeller slip is the difference between the theoretical and effective pitch or the distance lost by the propeller in one revolution.

Propeller thrust is the force impelled by the propeller to the point of application.

Propeller torque is the rotary force of the propeller. It produces an opposite rotary motion to the point of application.

Protractor is an instrument used for measuring angles.

Pusher machine is an aëroplane with the propeller in the rear.

Rib is a curved wooden frame used in a wing to give it camber, carry the fabric and transfer the lift from the fabric to the spars. A rib is composed of three parts: a web and two cap strips. If the web is thick and solid, the rib is called a compression rib; if the web is thin and lightened by means of holes bored in it, the rib is called a camber rib. There is also a false rib, which is a strip of wood tacked on the upper front part of a wing to prevent the fabric from sinking between the ribs proper.

Rigging or flying position is the position assumed by the fuselage when its engine rails are level both longitudinally and laterally.

Rivet is a short bolt without a thread.

Root end of a wing is its thick end to which are attached the hinges.

Rudder is a controlling plane hinged vertically to the rear of a machine to steer it to the right or left.

Rudder post is a steel tube to which is hinged the rudder.

Safety wire is a fine solid wire used to lock a turnbuckle; or to tie aëroplane wires together or to some part of the machine, to avoid their falling in the way of the propeller in case of a break.

Screw propeller is a section of a screw. It screws itself into the air and converts a rotary motion into a linear motion. This definition conforms with the old theory of the propeller; according to the new theory, a propeller is a revolving inclined plane.

Serving is the protective wrapping of a cord or a wire around a splice.

Sextant is an instrument for measuring the angular distance between two objects by means of a graduated arc, representing the sixth part of a circle, and a double reflection from two mirrors.

Shear stress is the stress that tends to tear a body in such a manner as to cause one part to slide over the other.

Shielding is the protection against the air resistance offered by a body on another following in its wake within certain limits and producing a decrease in passive drift.

Side slip is the sideways motion of an aëroplane toward the center of a turn as a result of excessive banking.

Sine. See Trigonometry.

Skid is a piece of wood, cane or tubing used for supporting or allowing to move on it some part of an aëroplane, as the tail, undercarriage or wing tips.

Skid (to skid) is to cause an aëroplane to move sideways away from the center of a turn as a result of insufficient banking.

Skin friction is the rubbing of the air against the layer of air surrounding the surface of a moving body.

Span is the length of the main plane of an aëroplane, measured from tip to tip, excluding the extension when used.

Spar is a long piece of wood within a wing to which the ribs are attached.

Stability is the tendency of a body to keep its state of equilibrium. In an aëroplane there are three kinds of stabilities: longitudinal or in a fore and aft direction; lateral or from port to starboard; directional or from right to left.

Stabilizing plane is a plane that gives inherent stability to a machine. There are two stabilizing planes: horizontal and vertical stabilizer.

Stagger is the step disposition of planes, either forward or backward.

Stagger and incidence wires are the internal cross bracing wires of the wings.

Stall is to stop the forward motion of an aëroplane through an excessive angle of attack.

Straight edge is a long piece of wood or metal having the edges perfectly straight, used to ascertain whether a surface is exactly even.

Strain is the deformation produced by an overstress.

Stream-line is the line traced by the successive positions of a particle of moving fluid. It is a continuous curve, as a fluid can not instantly change its direction of flow without forming a detrimental surface of discontinuity.

Stress is the load to which a body is subjected.

Stringer is a long strip of wood running the full length of the wing through the web of the ribs to prevent them from rolling over.

Strut is a piece of wood which holds apart two other pieces of wood.

Sweepback is the rearward position assumed by the wings when their leading edges form angles with the lateral axis of an aëroplane.

Tail post is the strut at the extreme tail end of the fuselage.

Tail skid is a piece of wood attached under the tail of a machine to carry the weight of its rear portion while on the ground and to act as a shock absorber and brake in landing.

Tail slide is a tail first plunge of an aëroplane.

Tension is the stress which tends to elongate a body.

Thrust drift ratio is the proportion of the thrust to the drift of a propeller.

Torsion is a combination of the compression, tension and shear stresses.

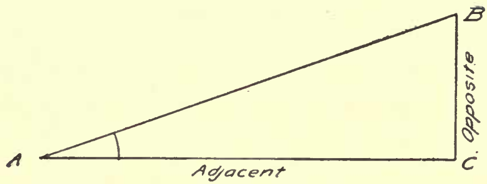
Tractor machine is an aëroplane with the propeller in front.

Trailing edge is the rear edge of a plane.

Trigonometry is that branch of mathematics which treats of the relations of the sides and angles of triangles.

In studying these relations, the right-angled triangle is taken as a base, and the ratio of the sides and hypotenuse taken by two in three different ways, forming six ratios in all, are given different names.

In any right-angled triangle



92

$A\ B\ C$, C being the right angle, with reference to the angle A, let $B\ C$ be denoted the opposite side, and $A\ C$ the adjacent side. Then we will have:

sine A, abbreviated sin $A = \dfrac{\text{opposite side}}{\text{hypotenuse}}$

cosine A " cos $A = \dfrac{\text{adjacent side}}{\text{hypotenuse}}$

tangent A " tan $A = \dfrac{\text{opposite side}}{\text{adjacent side}}$

cotangent A " cot $A = \dfrac{\text{adjacent side}}{\text{opposite side}}$

secant A " sec $A = \dfrac{\text{hypotenuse}}{\text{adjacent side}}$

cosecant A " cosec $A = \dfrac{\text{hypotenuse}}{\text{opposite side}}$

The numbers which indicate these ratios have already been determined and tabulated for all angles from one to ninety degrees. So that when we want to know the value of these six ratios for a given angle, we have to look into the tables of the natural functions of angles. As in our calculations we use mostly sines and cosines, having only in one instance the use of tangents, we will confine our study to them only.

The sum of the angles of a triangle is equal to two right angles. A right angle is ninety degrees (90°). As we take as a base the right-angled triangle, it is evident that, C being one right angle, $A + B$ is equal to one right angle. Consequently, if $A = 1°$, $B = 89°$; $A = 2°$, $B = 88°$; $A = 44°$, $B = 46°$; $A = 45°$, $B = 45°$; $A = 46°$, $B = 44°$; $A = 88°$, $B = 2°$; $A = 89°$, $B = 1°$. From

this, we see that after we reach an angle of 45°, the process is reversed; that is, the sine of an angle of 1° is the cosine of an angle of 89°, and vice versa. Therefore, instead of tabulating first all the sines of the angles from 1° to 90° and then the cosines from 1° to 90°, we can tabulate the sines only or, as it is commonly done, we can write all the sines from 0° to 45° and the cosines from 90° to 45°, so arranged that to the sine of an angle corresponds its cosine, and vice versa. Where greater precision is required, the tables are compiled to give the ratios for fractions of degrees, that is, minutes, as one degree is sixty minutes (60′).

For our calculations, the functions of entire degrees being sufficient, the following table of sines and cosines will do:

Natural Sines and Cosines

°	sin	cos	°	°	sin	cos	°
0	0.00000	1.00000	90	23	0.39073	0.92050	67
1	0.01745	0.99985	89	24	0.40674	0.91355	66
2	0.03490	0.99939	88	25	0.42262	0.90631	65
3	0.05234	0.99863	87	26	0.43837	0.89879	64
4	0.06976	0.99756	86	27	0.45399	0.89101	63
5	0.08716	0.99619	85	28	0.46947	0.88295	62
6	0.10453	0.99452	84	29	0.48481	0.87462	61
7	0.12187	0.99255	83	30	0.50000	0.86603	60
8	0.13917	0.99027	82	31	0.51504	0.85717	59
9	0.15643	0.98769	81	32	0.52992	0.84805	58
10	0.17365	0.98481	80	33	0.54464	0.83867	57
11	0.19081	0.98163	79	34	0.55919	0.82904	56
12	0.20791	0.97815	78	35	0.57358	0.81915	55
13	0.22495	0.97437	77	36	0.58779	0.80902	54
14	0.24192	0.97030	76	37	0.60182	0.79864	53
15	0.25882	0.96593	75	38	0.61566	0.78801	52
16	0.27564	0.96126	74	39	0.62932	0.77715	51
17	0.29237	0.95630	73	40	0.64279	0.76604	50
18	0.30902	0.95106	72	41	0.65606	0.75471	49
19	0.32557	0.94552	71	42	0.66913	0.74314	48
20	0.34202	0.93969	70	43	0.68200	0.73135	47
21	0.35837	0.93358	69	44	0.69466	0.71934	46
22	0.37461	0.92718	68	45	0.70711	0.70711	45
	cos	sin			cos	sin	

This is the table of the natural sines and cosines of angles, to be distinct from the logarithmic functions, which do not enter in our calculations.

If we want to know the sine and cosine of an angle of 10°, for instance, we look in the table for the angle of 10° and we find: sin 10° = 0.17365, cos 10° = 0.98481. If, instead, we look for the sine and cosine of an angle of 80°, we find: sin 80° = 0.98481, cos 80° = 0.17365. In this way, we will be able to find the sine and cosine of any angle.

If, as a result of our calculations, we find the sine of an angle and we want to know its value in degrees, we look for this sine in the tables and see what degree corresponds to it; but if we do not find a sine exactly equal to the one we are looking for, it means that the angle is not expressed by an entire number of degrees, and we have to look for it in more detailed tables.

Suppose, for instance, that we want to know what angle in degrees corresponds to the sine 0.105. In the table, we find that the nearest approach to it is sin 6° = 0.10453; therefore, the degree of our angle is between 6° and 7°; but, evidently, much nearer to 6° than it is to 7°. And if we look for it in a more detailed table, we find our angle expressed in degrees and factions of a degree or minutes.

Turnbuckle is a coupling with a barrel and a right hand and a left hand eye screw or shank used to regulate the length and tension of wires. The right hand screw shank, which sometimes is split or forked, is always attached to a fitting, while the left hand screw shank is attached to the wire. This is done to determine the turning direction of the barrel in tightening or loosening a wire, as, in this case, the operation is that of an ordinary right hand screw nut. The come and go is the distance the shanks can be screwed in or out.

Undercarriage is that part of an aëroplane designed to support it when at rest, to absorb the shock of landing and to give clearance to the propeller and wings.

Veneer is a thin layer of wood.

Vertical stabilizer or fin is a triangular plane bolted at the upper part of the horizontal stabilizer to give inherent directional stability to an aëroplane.

Volplane is a glide.

Wash in is an increase in the angle of incidence.

Wash out is a decrease in the angle of incidence.

Web is the central part of a rib.

Wind screen is a shield placed in front of the cockpit to protect the aviator from the effect of the wind.

Wind tunnel is a tube through which air is forced or drawn by means of rotating fans.

Wing is a fabric covered, cambered, wooden and metallic frame.

Wing tip is the extreme thin end of a wing opposite the root end.

INDEX

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